Capacity Improvement through Automated Airport Surface Traffic Control

Phase Two Self Assessment Results

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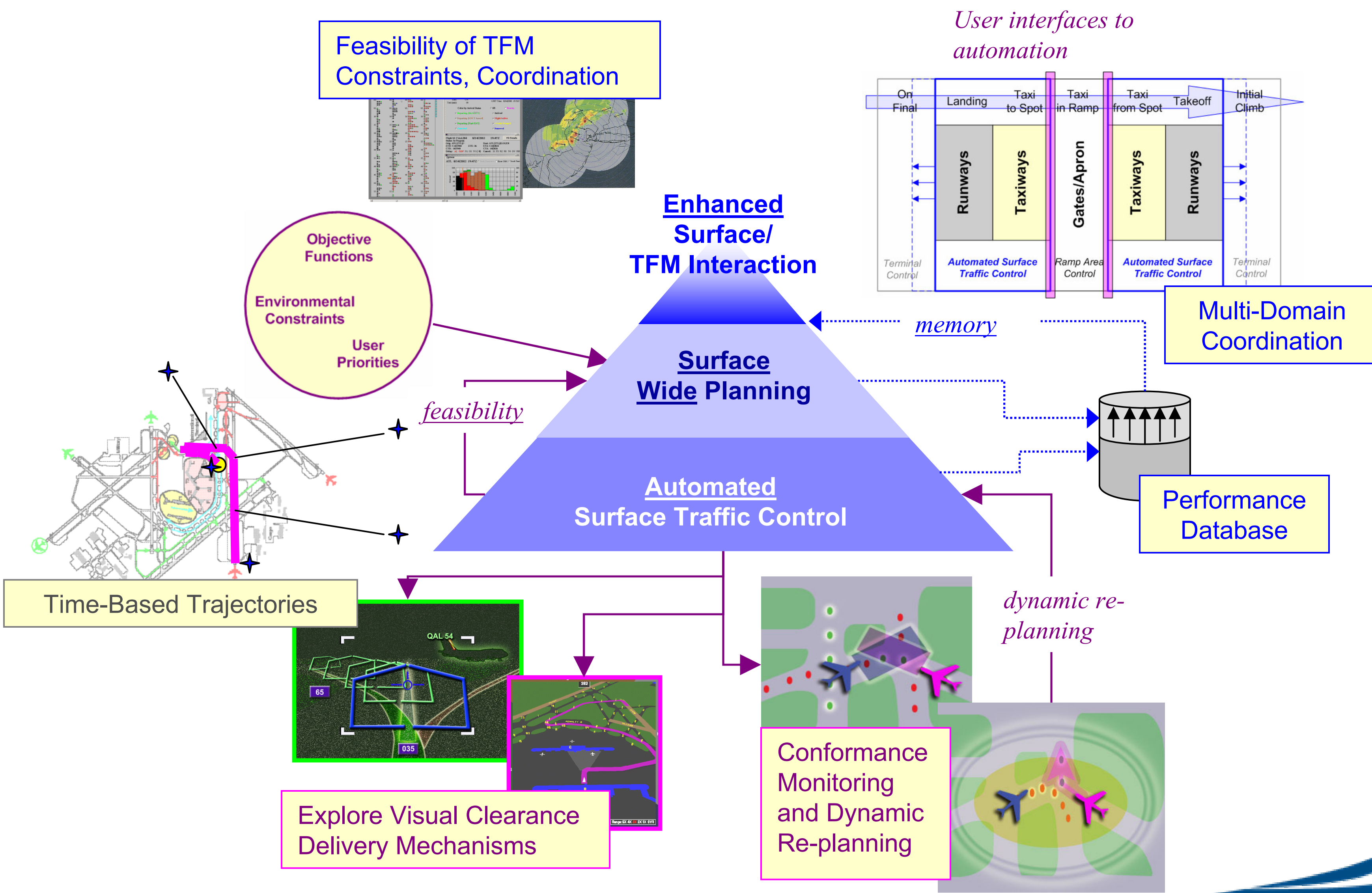
Outline

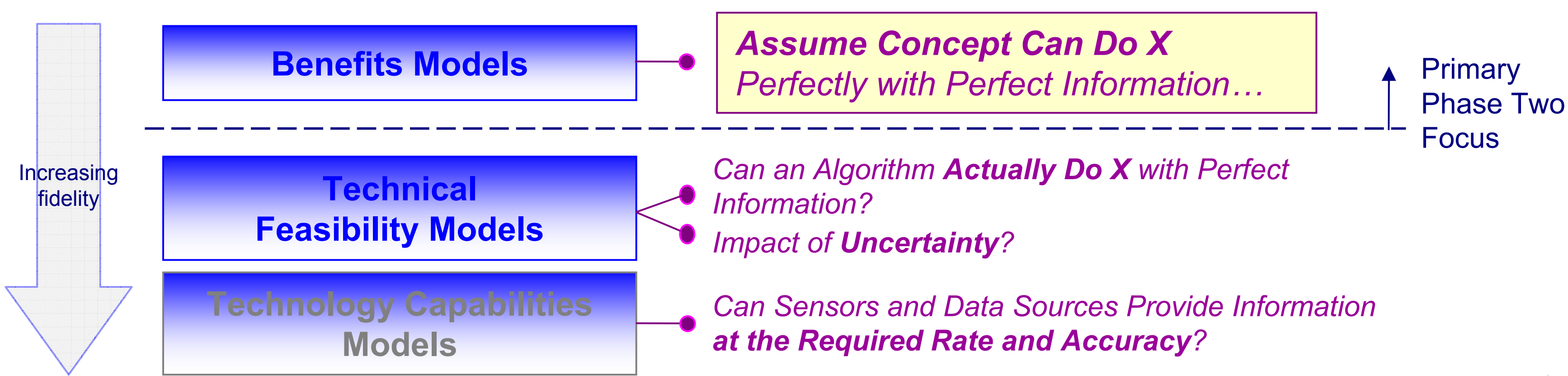
- Brief Review of Core Ideas
- Purpose/Scope of Phase Two Assessment
- Study Overview and Metrics
- Summary of Key Results
- Plans for Phase Three

Concept Overview: Core Ideas

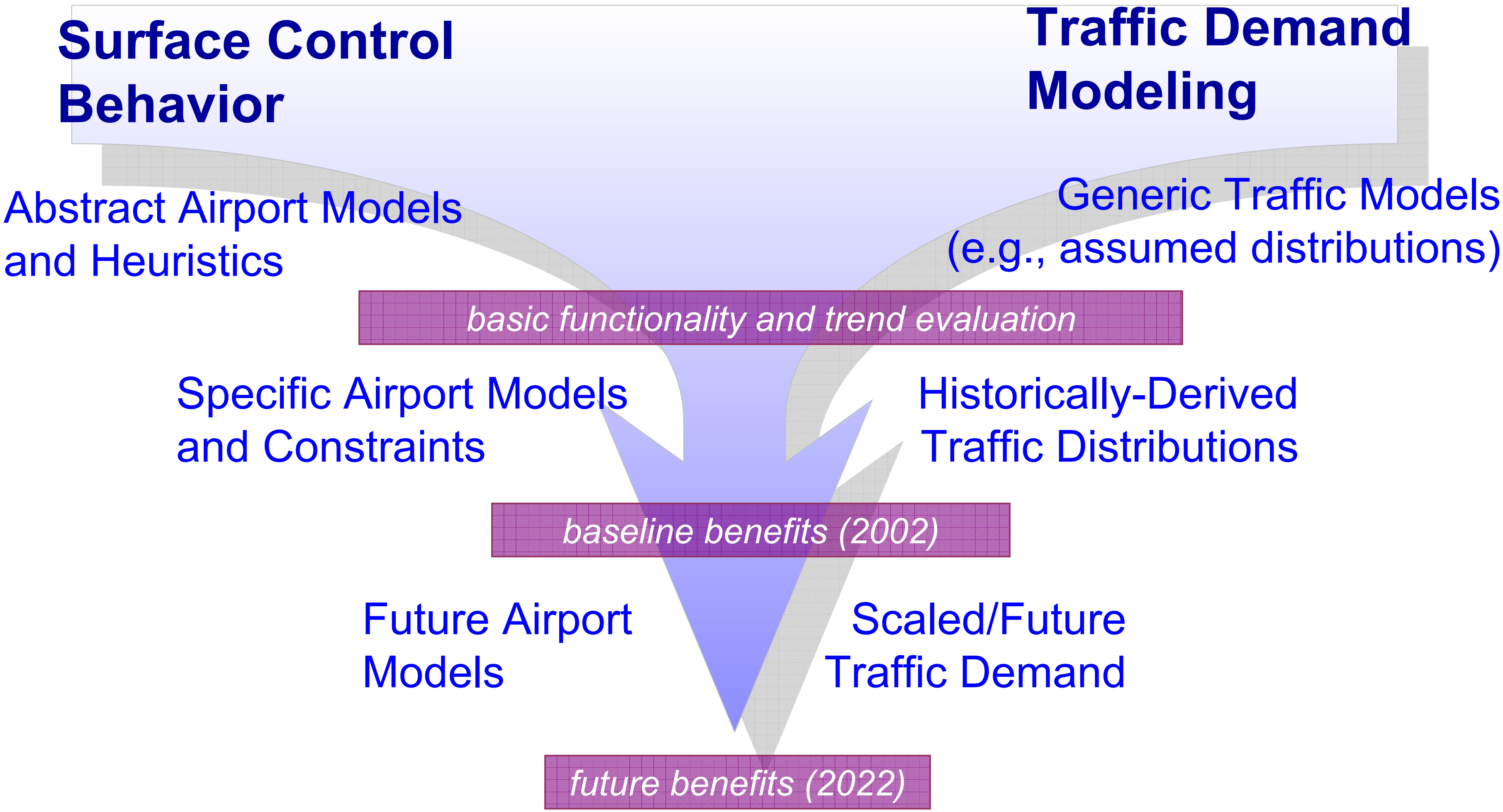


Context, Purpose and Scope for Phase Two

- **Goals:**
  - Begin to quantify benefits of concept elements
  - Establish technical feasibility of core concept functions/elements
  - Develop relationships useful for Phase Three evaluation in ACES
- **Approach:**
  - Local Experiments studying nominal behavior
  - Exercise specific benefit mechanisms in isolation
  - Compare models of concept against models of baseline
  - Develop environment for testing concept algorithms



Self-Evaluation Methodology



Phase Two Study Overview

- **Time-Based Scheduling Experiments**
  - Capture spatial aspects via time
  - Focus on runway scheduling and sequencing
  - Assume routings feasible

Surface/TFM Interactions

Runway Allocation

Pushback Scheduling

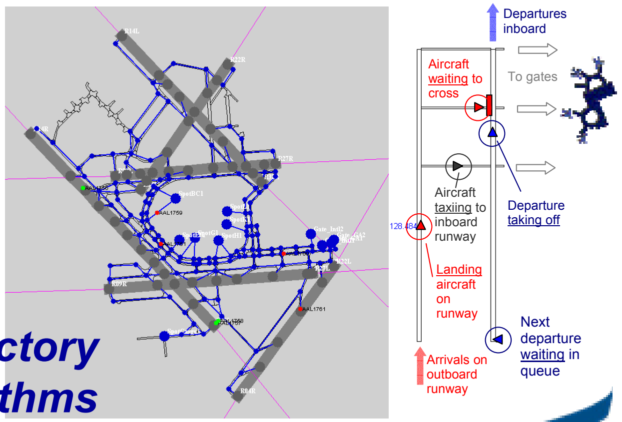
Configuration Change Efficiency

- **Physics-Based Modeling**
  - Model aircraft movement
  - Model physical constraints
  - Employ CD&R

Runway Crossing

Trajectory Planning Algorithms

Surface Simulation (RASEN)



Phase Two Benefit Mechanisms and Metrics

- **Time-Based Models/Experiments**

Benefit Mechanism:

Flow synchronization
Relaxed mapping

Runway Allocation

Departure delays
Runway throughput
<u>Workload</u>

Increased controllability

Pushback Scheduling

Reduced queuing
Runway throughput
<u>Environmental Impact</u>

Increased coordination
Explicit planning

Configuration Change Efficiency

Maintain runway throughput
Taxi and airborne delays

Increased controllability and predictability

Surface TFM Interactions

Constraint compliance
En route spacing

Metrics:

- **Physics-Based Models**

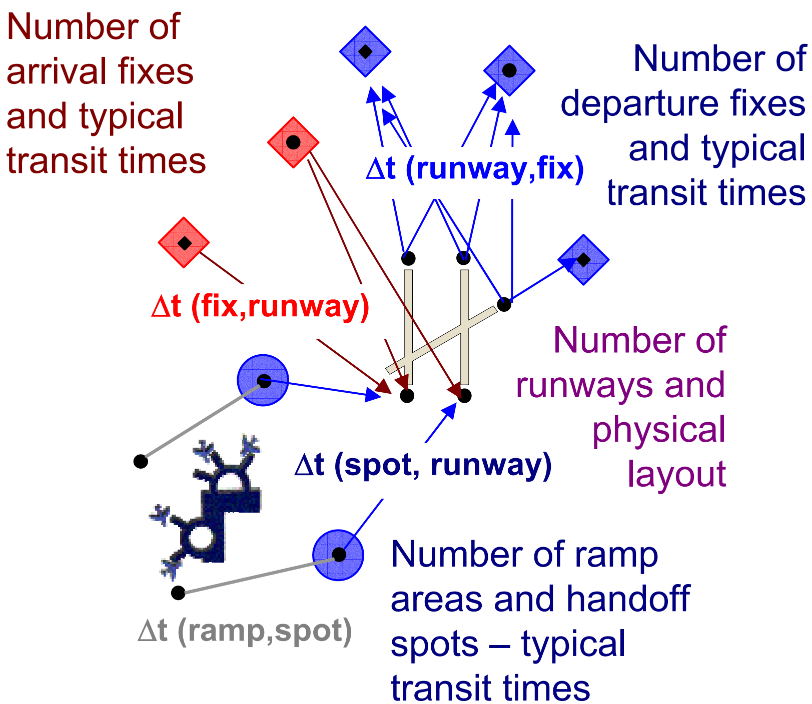
Flow synchronization,
explicit planning

Runway Crossing

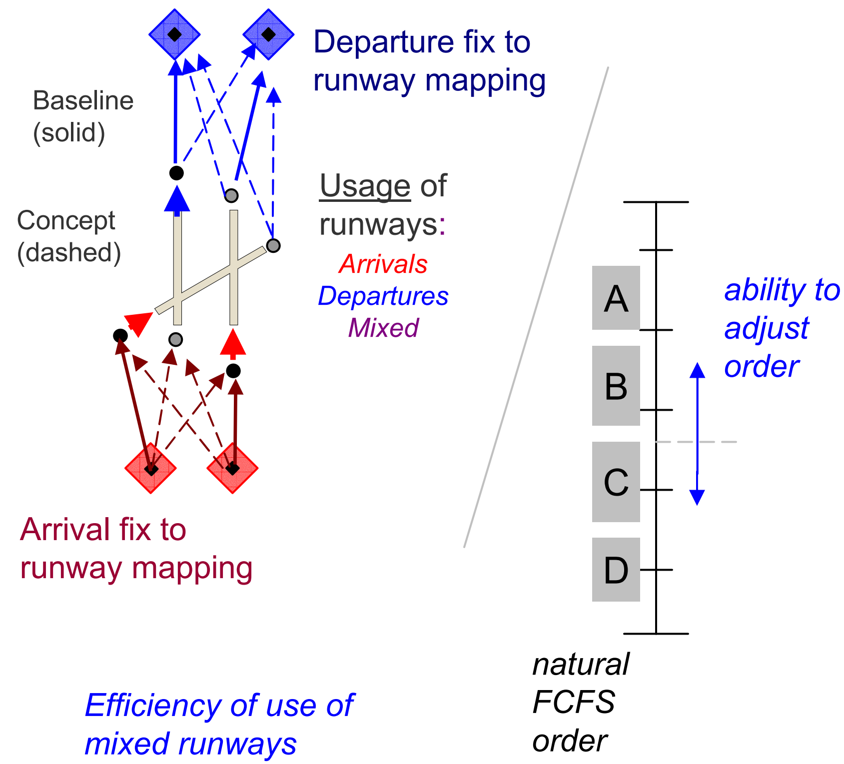
Taxi delays (efficiency)
<u>Environmental Impact (emissions)</u>

Phase Two Surface Modeling Description

Basic Modeling Features

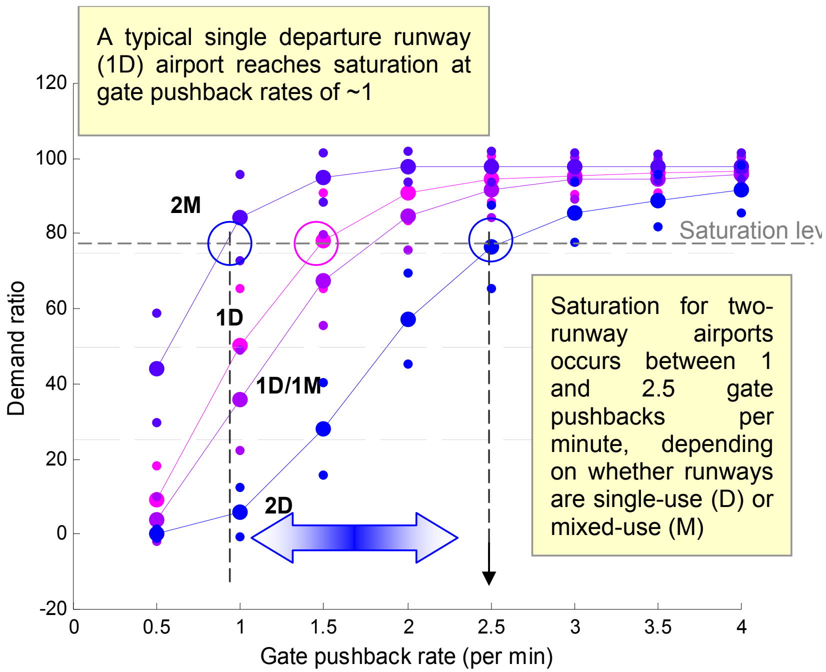


Modeling concept impacts

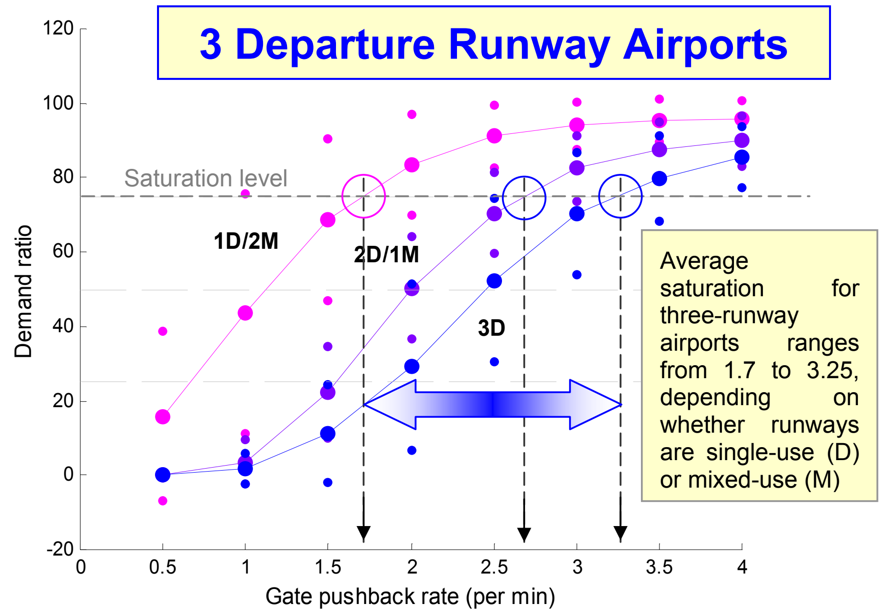


Normalizing Schedule Rates

- **Purpose:** Establish gate pushback rates consistent with airport "size" that lead to different levels of saturation

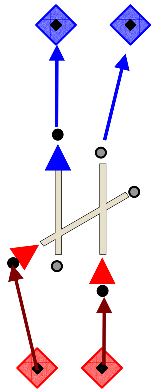


1-2 Departure Runway Airports

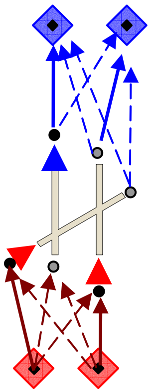


Runway Allocation Model: Approach

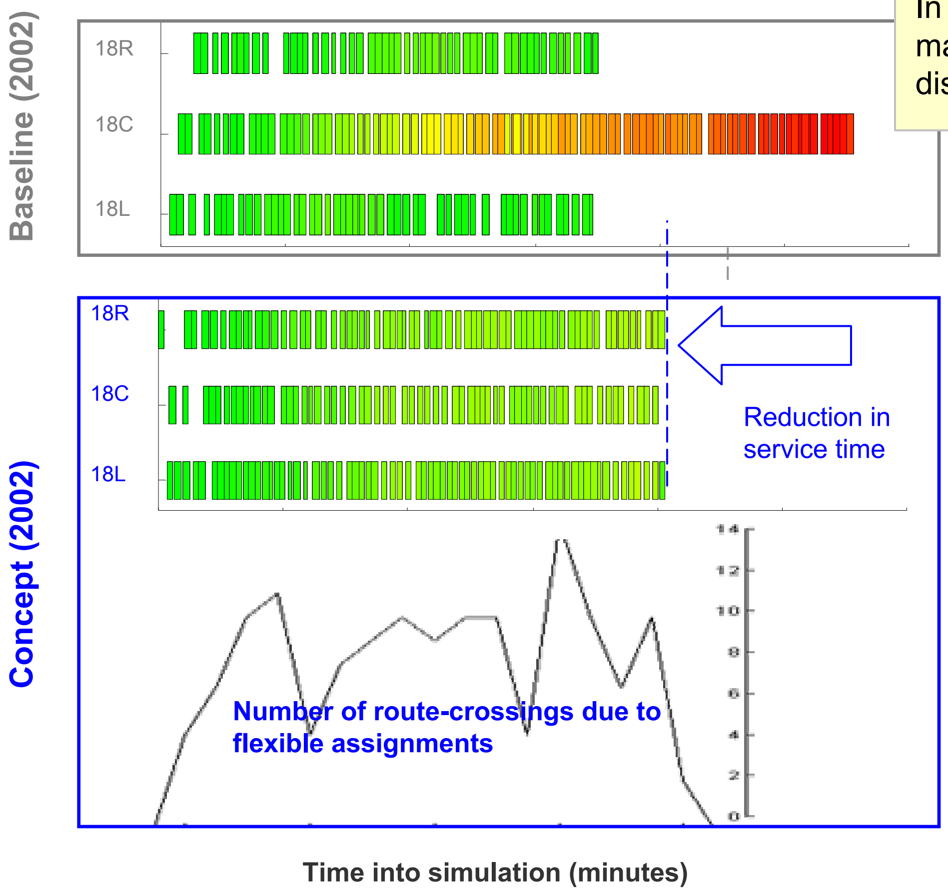
- **Baseline:**
  - **Runway assignment**: Static departure fix to runway mapping
  - **Runway scheduling**: First come, first served (FCFS)



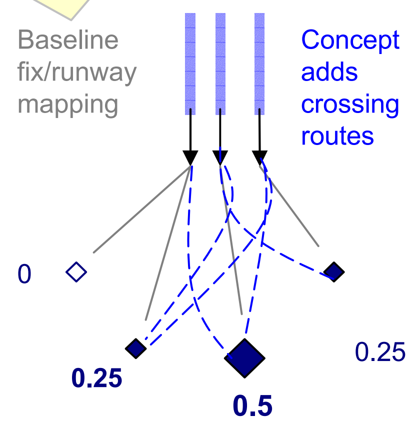
- **Concept:**
  - **Runway assignment/scheduling**: Heuristic algorithm putting flight on earliest available runway
  - **Assumption**: Flights can depart from any runway to reach any fix (e.g., 4D de-confliction in terminal airspace)



Runway Allocation Example – Mismatched Baseline



In the baseline case, the static mapping is ill-matched to the distribution of demand



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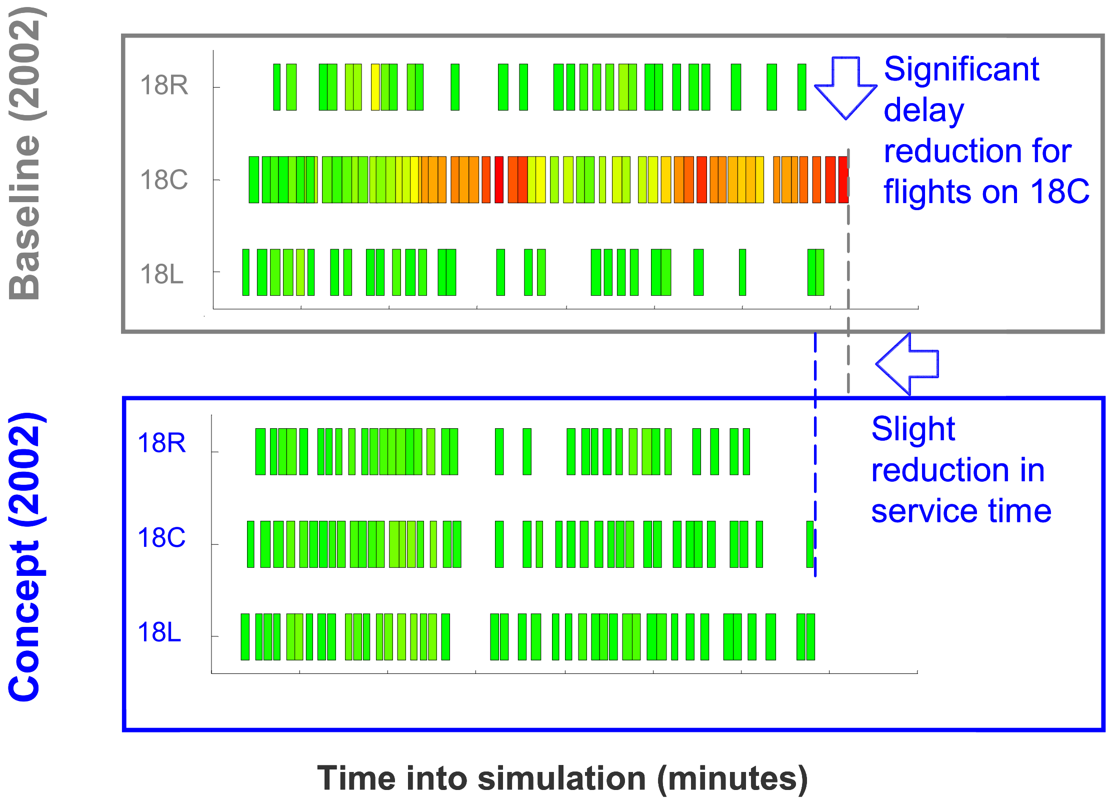
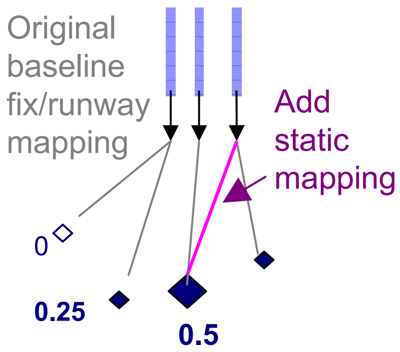
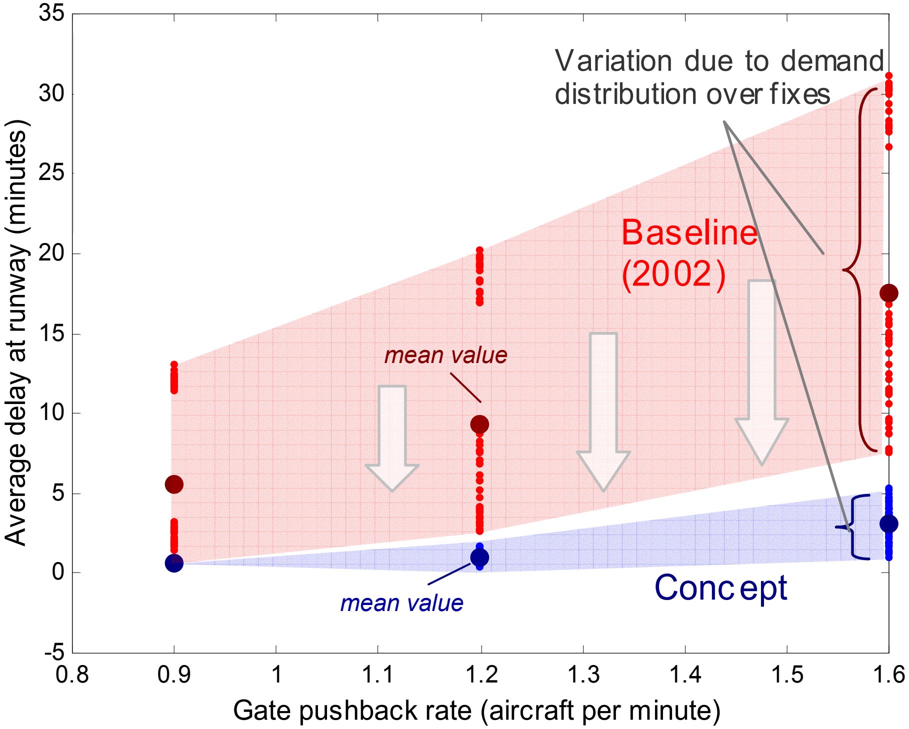
Runway Allocation Example – Improved Balancing

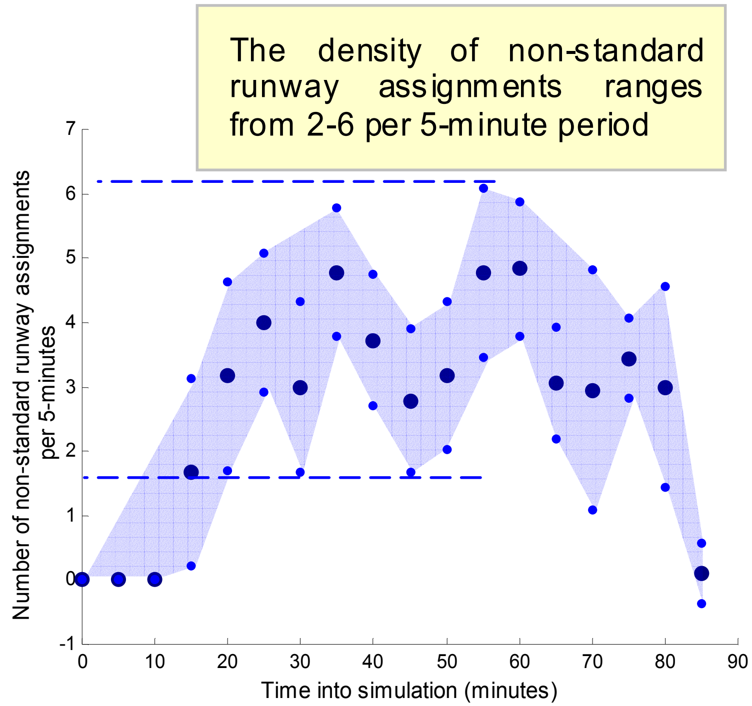




Runway Allocation Results – 2 Runway Airport

Airport model:
1 departure, 1 mixed-use





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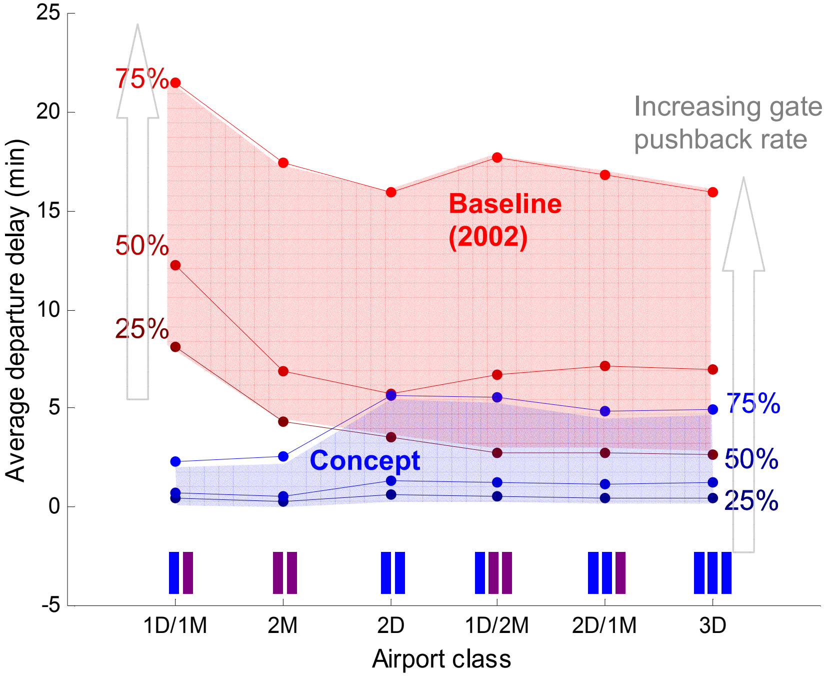
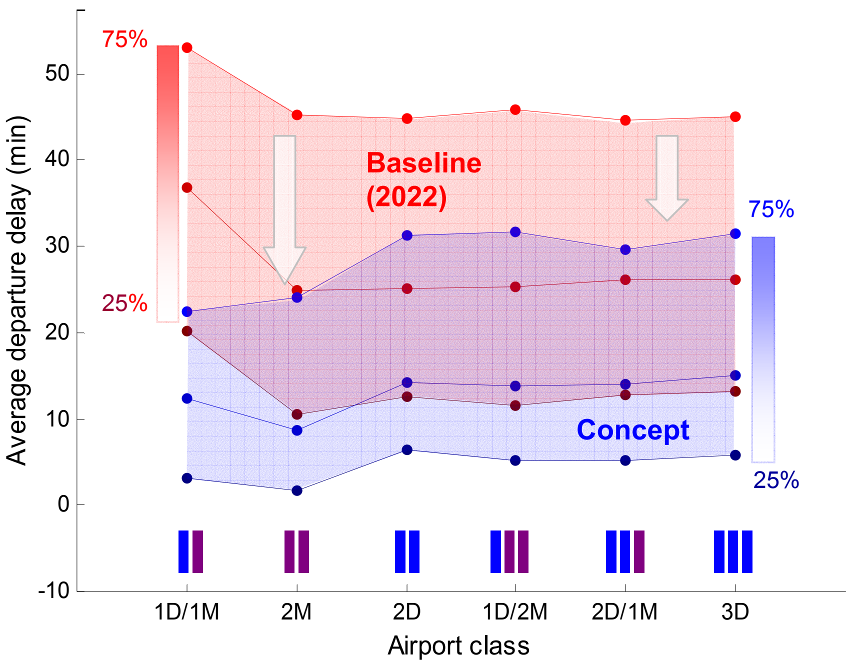
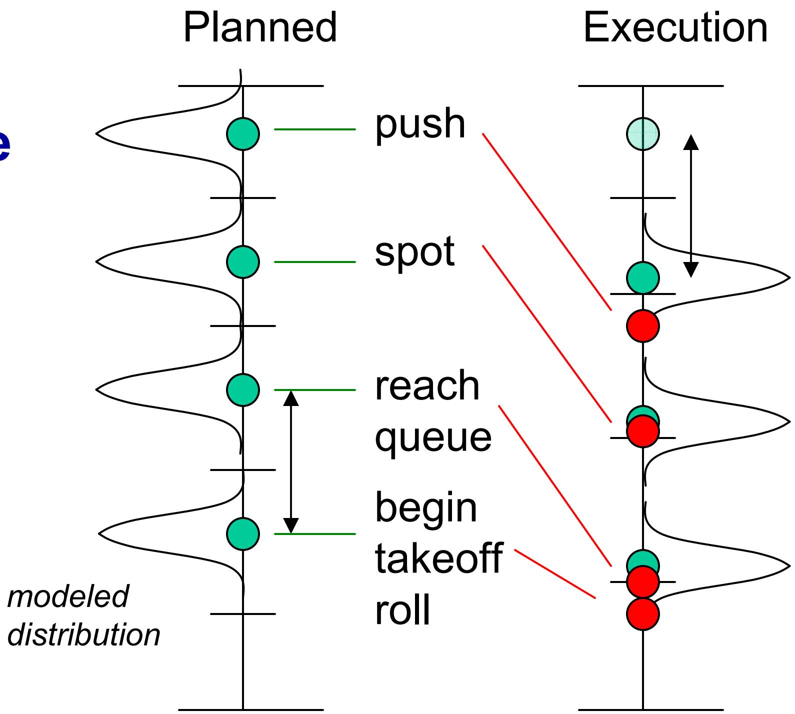
Runway Allocation: Airport Class Summaries





Pushback Scheduling Model: Approach

- **Provide planner with an estimate of earliest time to reach runway**
- **Model forward in time to estimate queuing for each aircraft**
- **Add queuing time (minus buffer) to scheduled pushback time**
- **"Execute" flights with errors injected between planner and actual values**
  - Pushback time
  - Ramp taxi time
  - Handoff at spot
  - Taxi time to runway (queue)



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Pushback Scheduling Model

- **Results:**

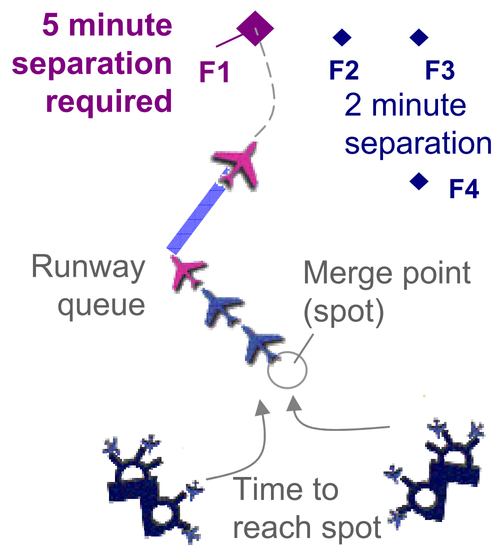
Model	Buffer (min)	Pushback Error	Delay At Spot	Taxi Time Error	Total Engine On Time (min)	Average Queue Time (min)	Average Pushback Shift (min)	% Controlled Flights
Concept 1	**0**	**N**	**N**	**N**	**2859**	**1.07**	**8.57**	**93%**
Concept 2	3	N	N	N	3070	2.53	7.67	71%
Concept 3	3	N	N	Y	3048	2.19	7.67	71%
Concept 4	3	N	Y	Y	3130	2.44	7.67	71%
Concept 5	3	Y	Y	Y	3152	2.63	7.67	71%
Baseline (FCFS)	**N/A**	**Y**	**Y**	**Y**	**3668**	**7.98**	**N/A**	**N/A**

With perfect information, concept leads to a savings of ~7 minutes in queuing time per flight

Pushback Scheduling Model: Case Study

- **Focus on ramp control and pushback policies related to the number of flights in queue**

Flight ID	Filed Out (Z)	Minimum Time to Reach Merge (min)	Filed Departure Fix
ABC1491	**836**	**11**	**F1**
ABC1507	**836**	**10**	**F1**
ABC1547	836	9	F2
ABC1431	**836**	**9**	**F1**
ABC1429	836	11	F3
ABC1447	**836**	**8**	**F1**
ABC1406	836	6	F4
ABC1410	**842**	**9**	**F1**
ABC1471	**842**	**8**	**F1**
ABC1525	**842**	**6**	**F1**



Pushback Scheduling Model (2)

- **Comparison of "Current World" Pushback Heuristics**

Heuristic	Expected Cost ($)	Expected Time All Flights Departed	Expected (Max) Per-Flight Delay at Gate Once Ready (min)	Expected (Max) Time In Queue Once Reaching Merge Point (min)
Baseline (Push Immediate)	11,203	0917Z	0 (0)	9.3 (29)
Keep 9 Flights Active	11,136	0917Z	0.2	9.1
Keep 8 Flights Active	10,963	0917Z	0.8 (9)	8.4 (29)
Keep 7 Flights Active	**10,734**	**0917Z**	**1.6 (14)**	**7.5 (26)**
Keep 6 Flights Active	11,023	0917Z	4.1 (19)	6.5 (19)
Keep 4 Flights Active	11,040	0921Z	10.2 (28)	2.7 (13)
Keep 2 Flights Active	14,949	0944Z	25.9 (56)	0.6 (5)

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Pushback Scheduling Model (3)

- **Improving on Current World Heuristics:**

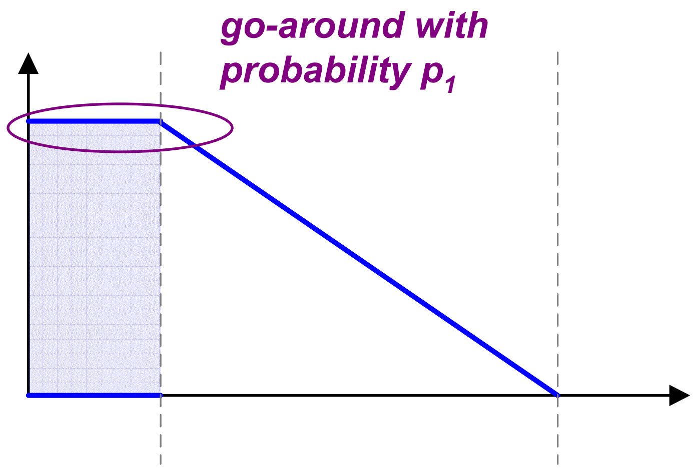
Heuristic	Expected Cost ($)	Expected Time All Flights Departed	Expected (Max) Per-Flight Delay at Gate Once Ready (min)	Expected (Max) Time In Queue Once Reaching Merge Point (min)
Baseline (Push Immediate)	11,203	0917Z	0 (0)	9.3 (29)
Keep 7 Flights Active	10,734	0917Z	1.6 (14)	7.5 (26)
X=6, Y=8 Rule	10,535	0917Z	2.5 (18)	6.5 (24)
X=5, Y=8 Rule	**10,343**	**0917Z**	**3.5 (20)**	**5.6 (19)**
X=5, Y=8 Rule + Re-sequencing	**9,498**	**0917Z**	**4.6 (10)**	**3.8 (15)**

- *Push flights in the order in which they become available to push.*
- *Push a flight immediately if there are **fewer than X** aircraft currently taxiing to its runway.*
- *Do not push a flight if there are **Y aircraft currently taxiing** to its runway (Y>X).*
- *If the number of active flights for that runway is greater than X but less than Y, make the decision based on an **expected** monetary value calculation.*

Configuration Change Efficiency Model

- **Approach: Define "repositioning" delay as a function of aircraft state at the time of change**

Repositioning Delay Function



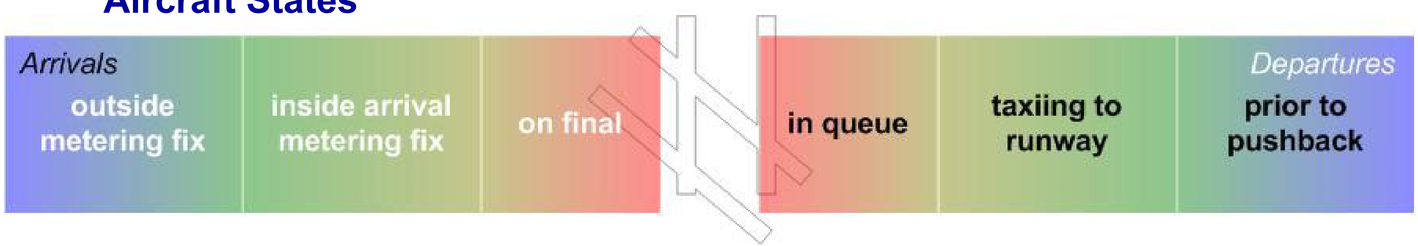
at change

Baseline: purely reactive response

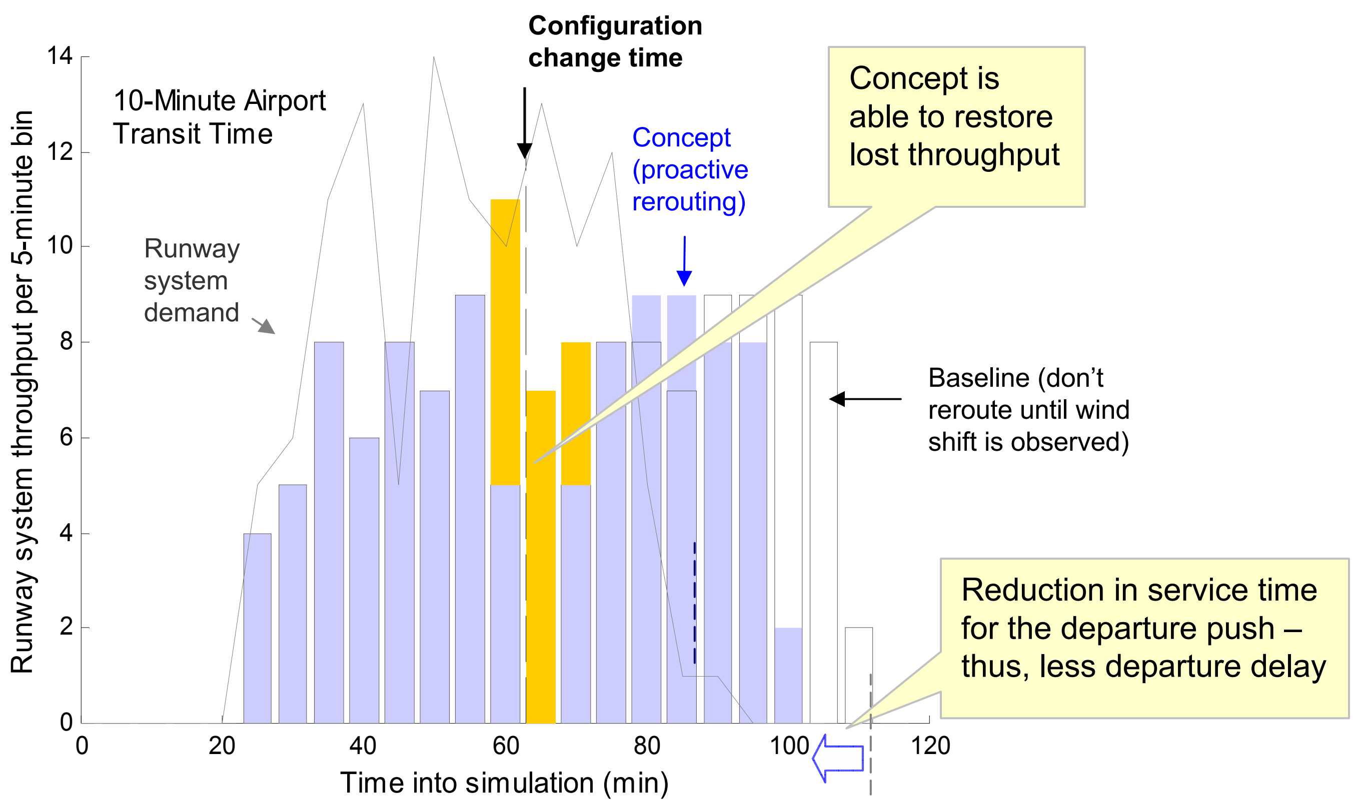
Concept: use forecast to anticipate change

What is the potential savings?

Aircraft States



Configuration Change Results: Perfect information



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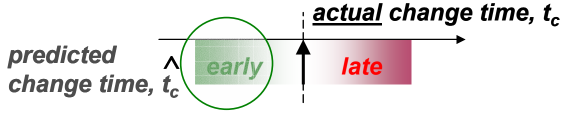
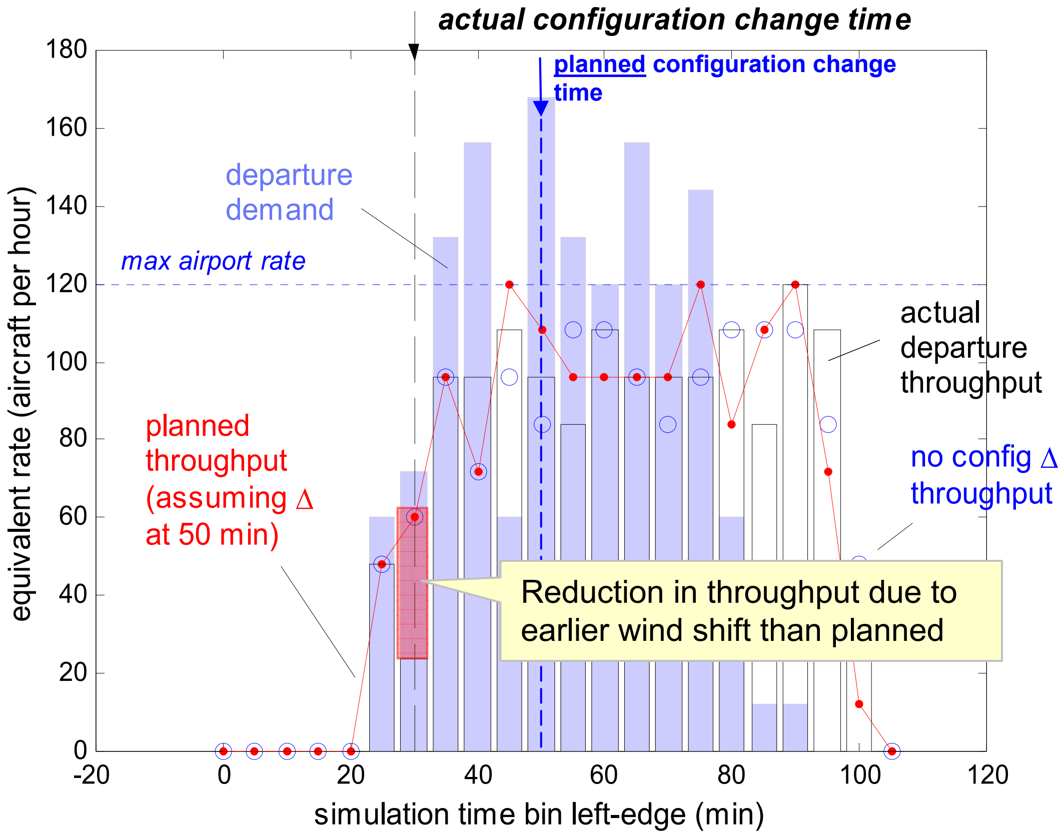
Configuration Change Model: Uncertainty Impact (1)

- **Sensitivity to <u>early</u> wind shift**
- **Relative to “no configuration change”**





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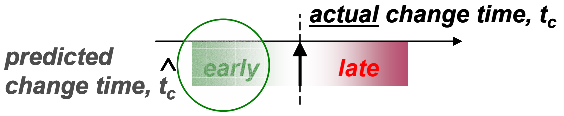
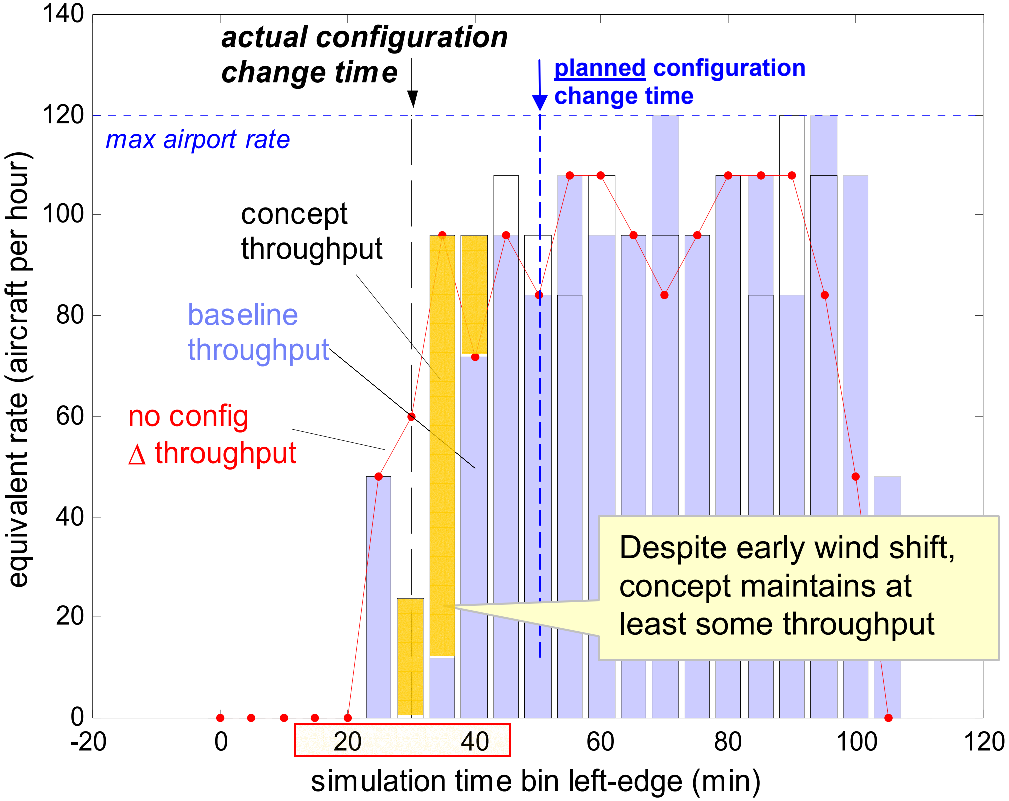
Configuration Change Model: Uncertainty Impact (2)

- **Sensitivity to <u>early</u> wind shift**
- **Relative to baseline, reactive policy**





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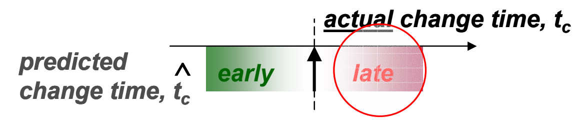
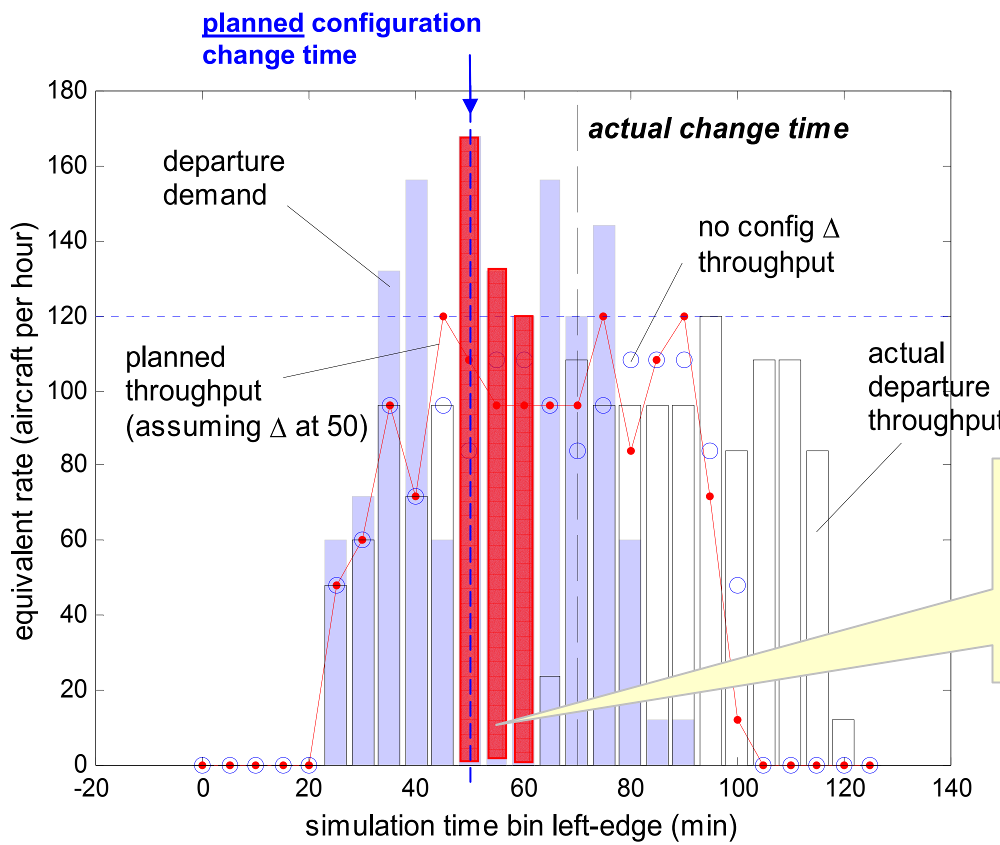
Configuration Change Model: Uncertainty Impact (3)

- **Sensitivity to <u>late</u> wind shift**



- **Relative to "no configuration change"**



When wind shift occurs <u>later</u> than planned, a void in runway throughput results

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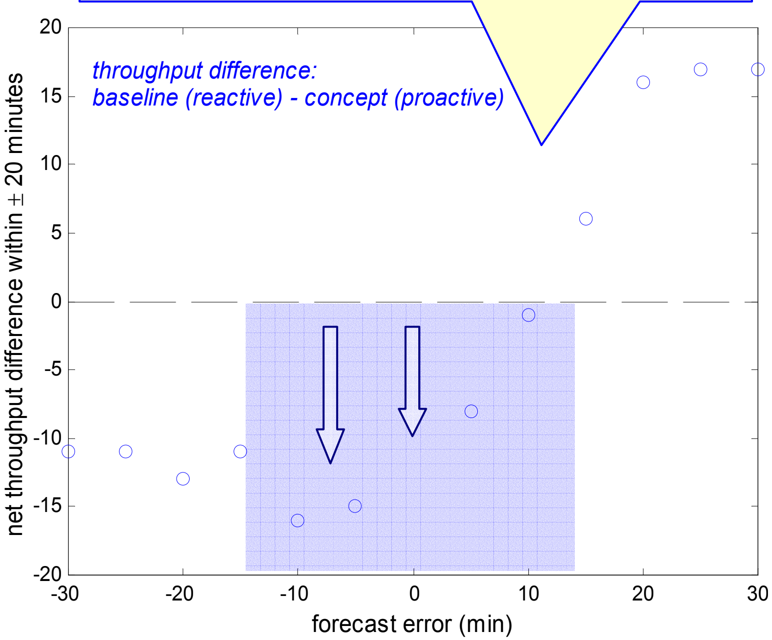
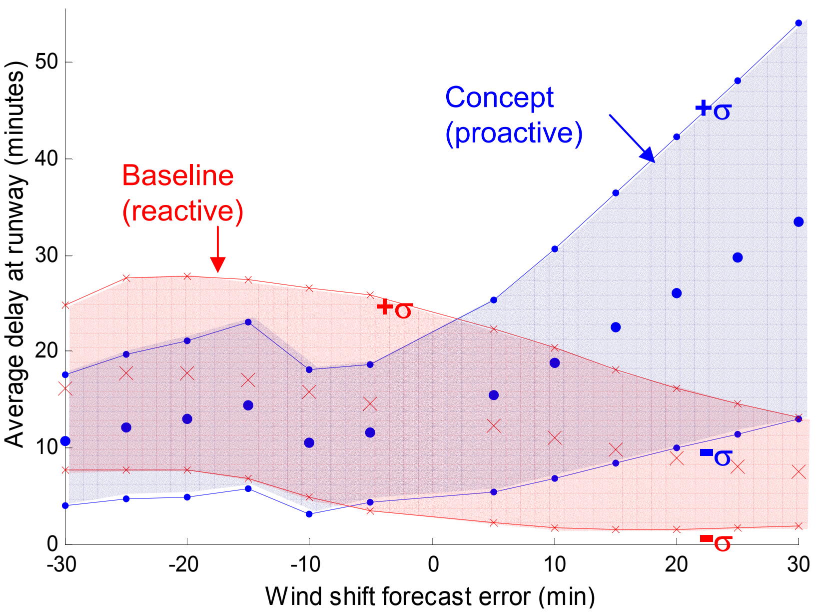
Configuration Change Model: Summary Results

Significant improvement in net throughput with forecast error less than +/- 10 minutes



Average departure delay remains consistent with that of the reactive strategy with forecast errors less than 10 minutes



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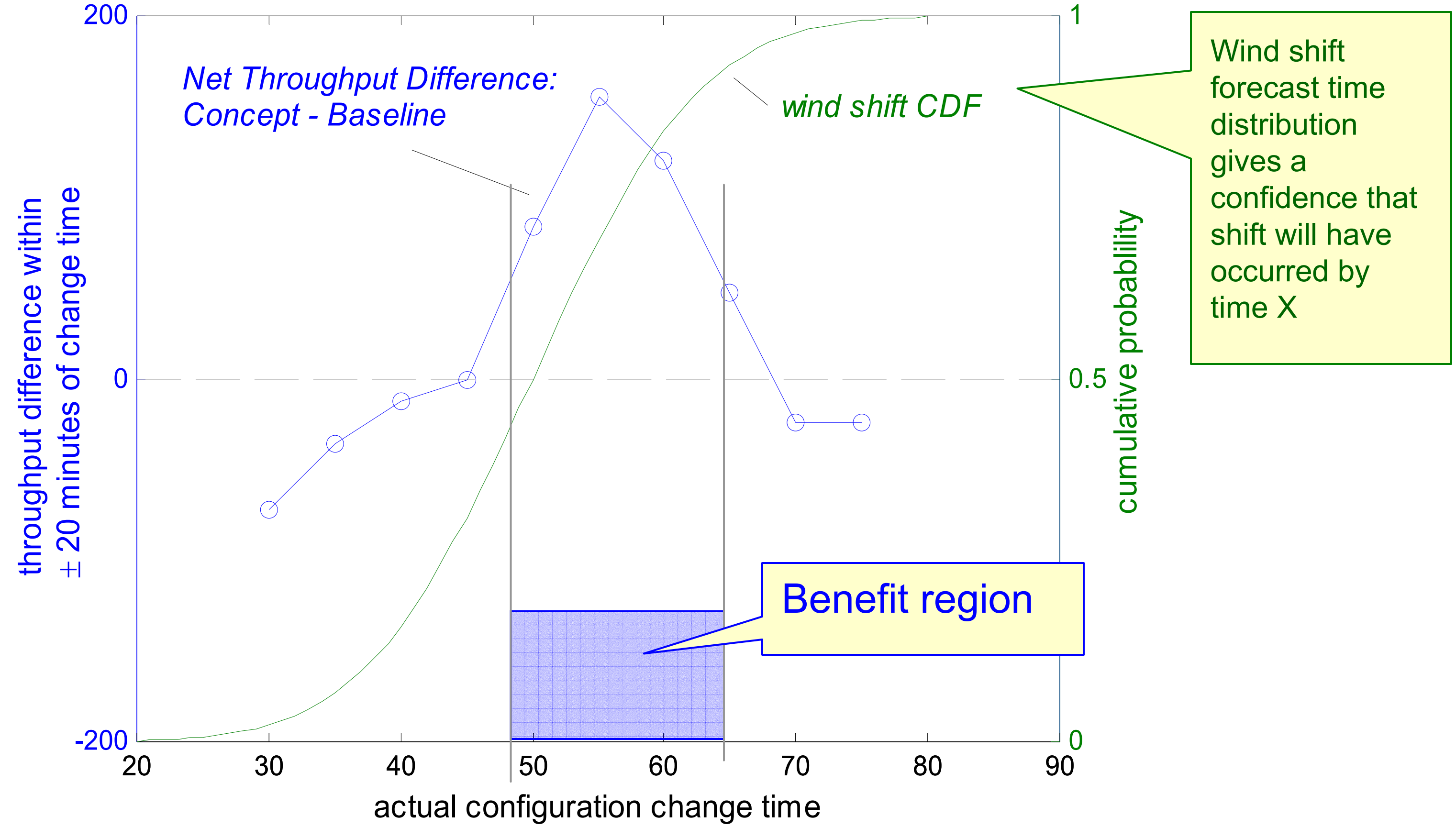
Configuration Change Model: CDF-Decisions

- **Use CDF as basis for assigning flights to “new” runways**



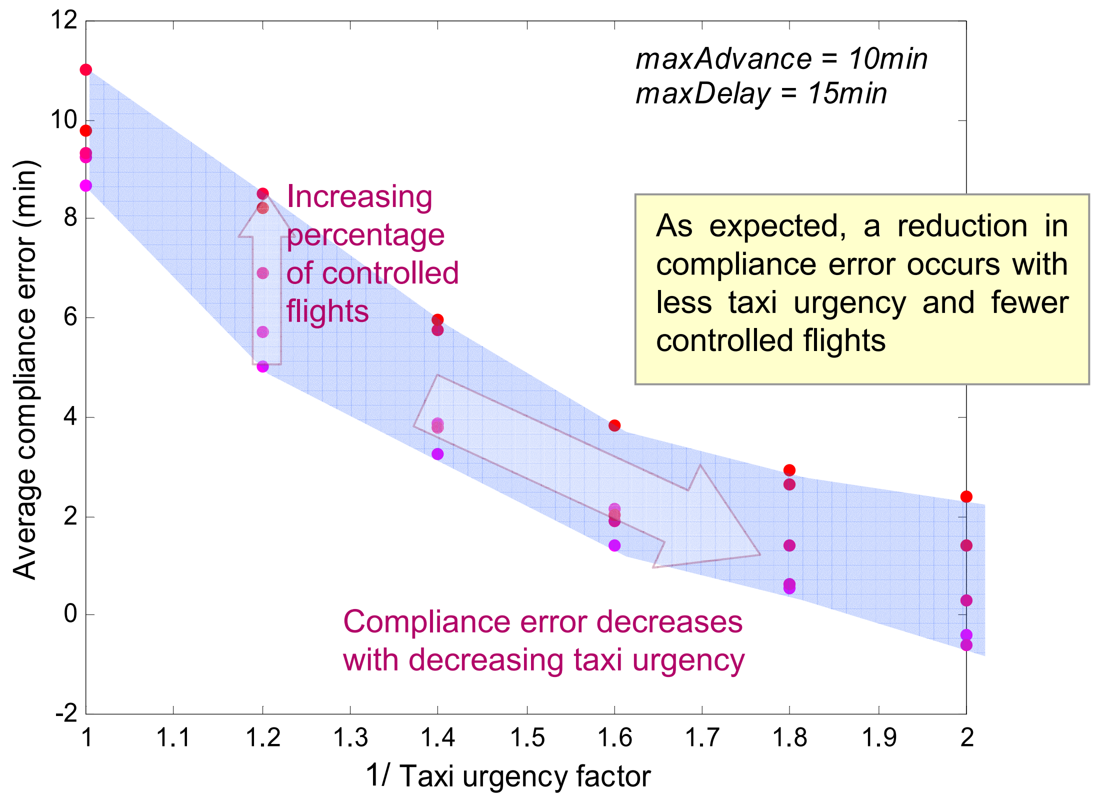
EDCT Compliance Model: Description

- **Approach:**
  - Planner gets "estimate" of pushback time and surface transit time to reach each runway
  - Automation capabilities reflected through max "advance" and max "delay" parameters
  - Vary percentage of flights with controlled off times
  - Airline "lead" time reflected through taxi urgency, defines controlled departure time

$$\text{Taxi urgency factor} = \frac{\text{(Unimpeded taxi duration)}}{\text{(EDCT – Pushback Time)}}$$

- **Metrics:**
  - Degree of compliance with controlled off time
  - Departure delay for uncontrolled flights
  - Runway system throughput

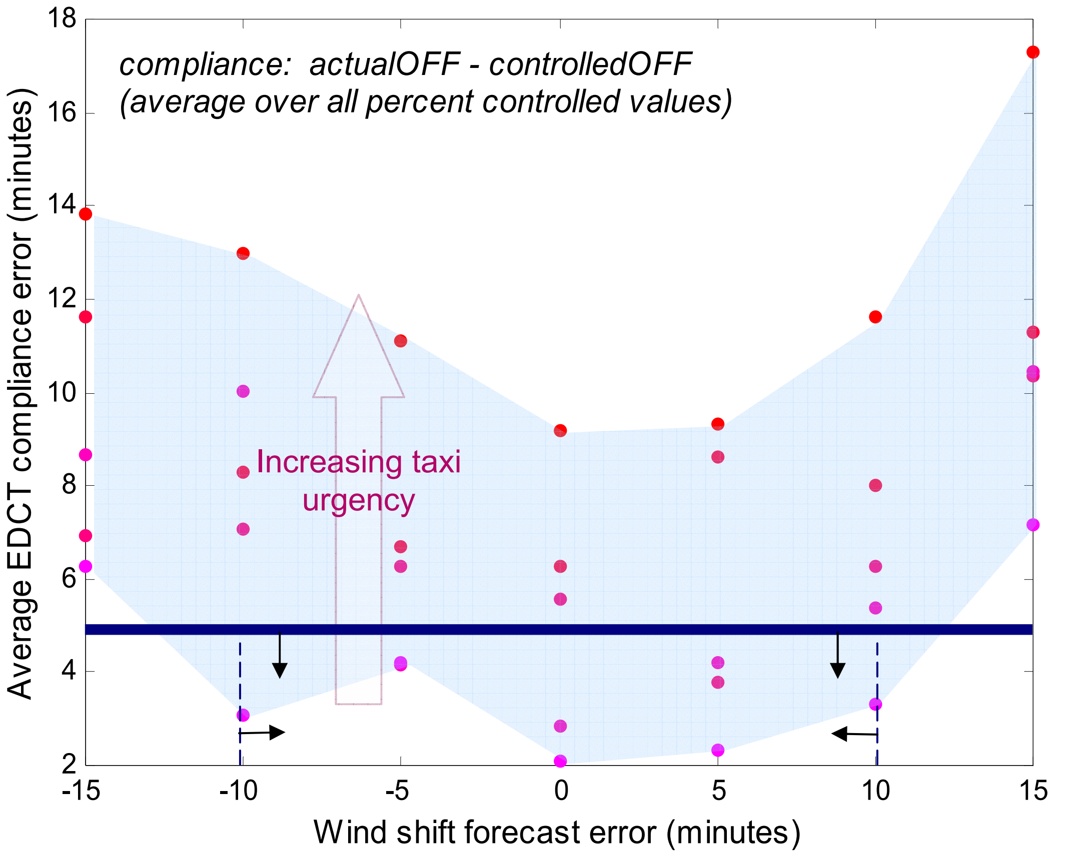
EDCT Compliance Model: Results



$$\textbf{Taxi urgency factor} = \frac{\textbf{(Unimpeded taxi duration)}}{\textbf{(EDCT – Pushback Time)}}$$

EDCT Compliance – Sensitivity to Wind Shift

- **Plan for wind shift at time t_c, look at behavior when forecast is in error**



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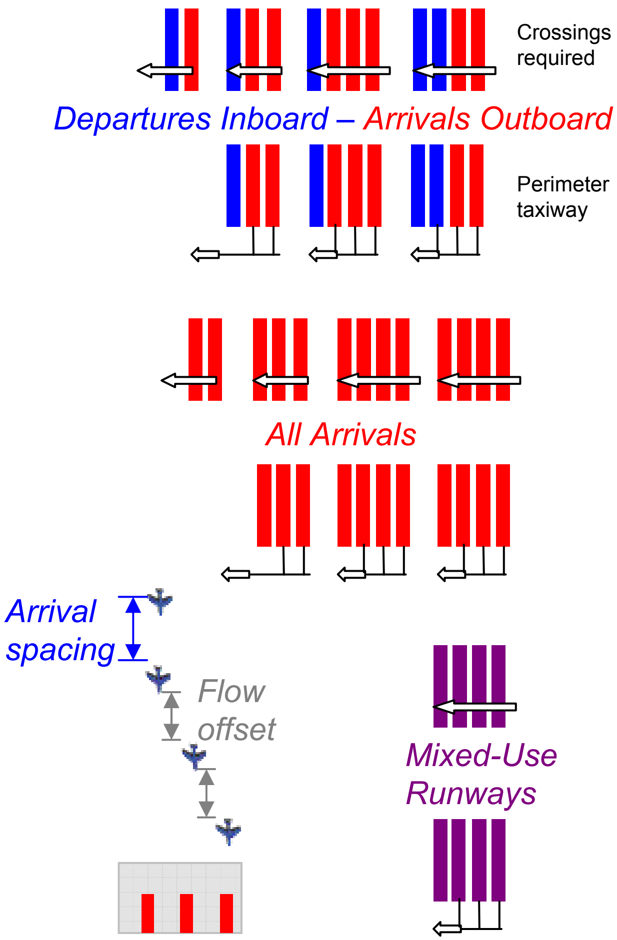
Runway Crossing Models

- **Purpose: Assess ability for concept to reduce taxi delays**
- **Physically model:**
  - Landing
  - Takeoff
  - Taxiing
- **Study Sensitivity to:**
  - Number of crossings necessary
  - Use of each runway
  - Offset between parallel flows
  - Inter-arrival spacing
  - Traffic mix
  - Crossing policy



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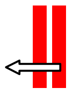
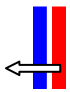
Single Runway Crossing Model

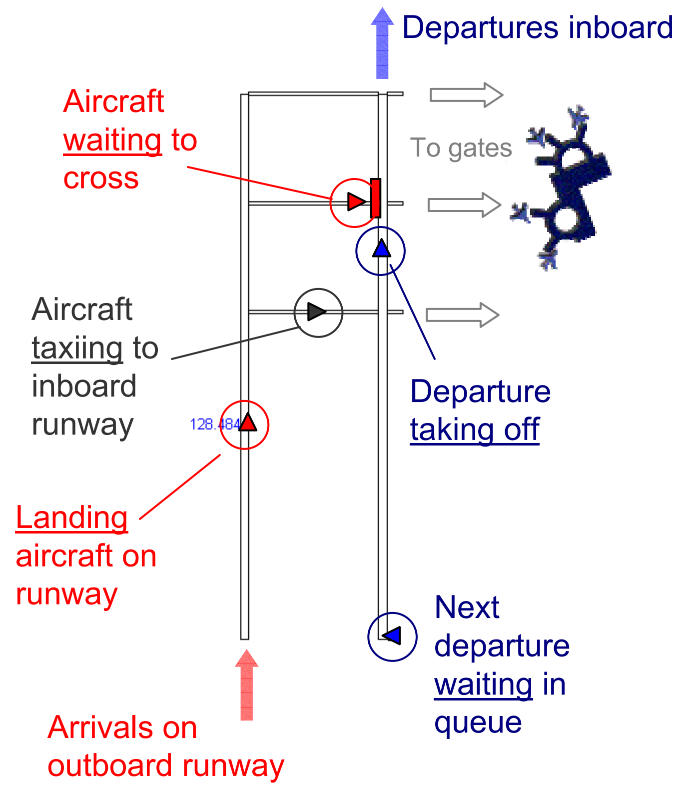


- **Arrivals Inboard**
  - Cross whenever large enough gap exists

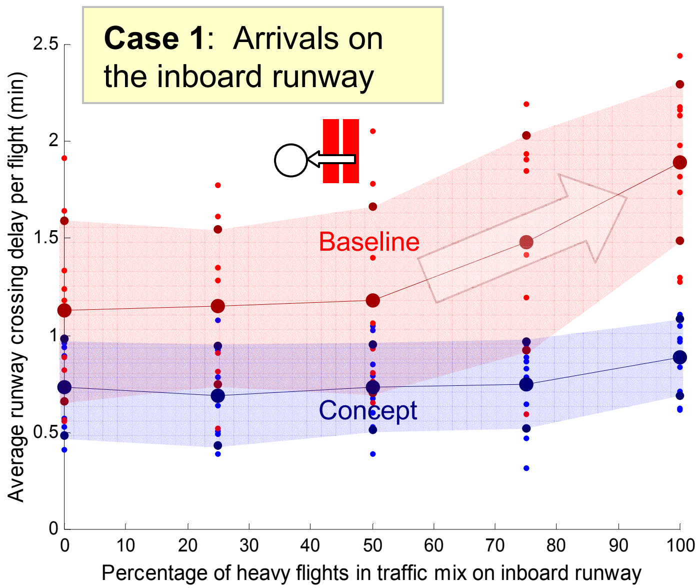


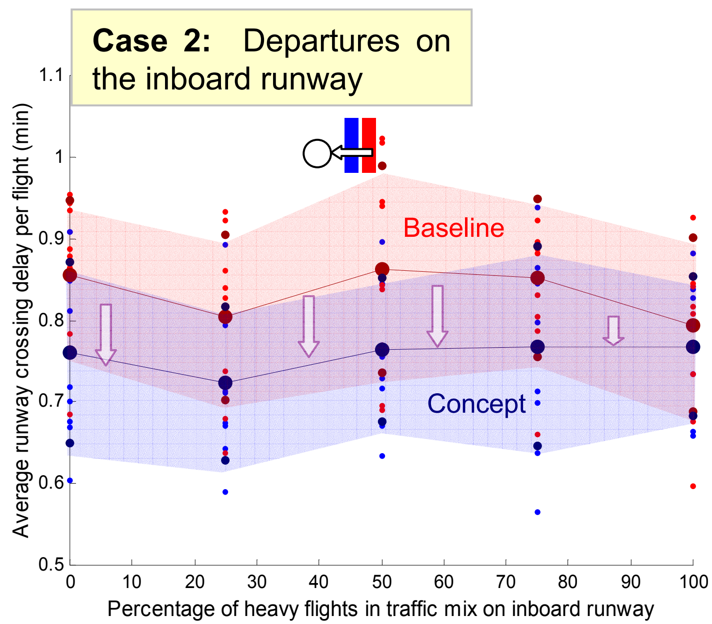
- **Departures Inboard**
  - Interleave Crossings and Departures
  - Cross in Waves
- **Model concept <u>effect</u> by modifying communication and response times:**

Model Case	Clearance Time (sec)	Engine Spool (sec)
Baseline (2002)	6	10
Concept	2	0



Runway Crossing Model Results: Single Crossing



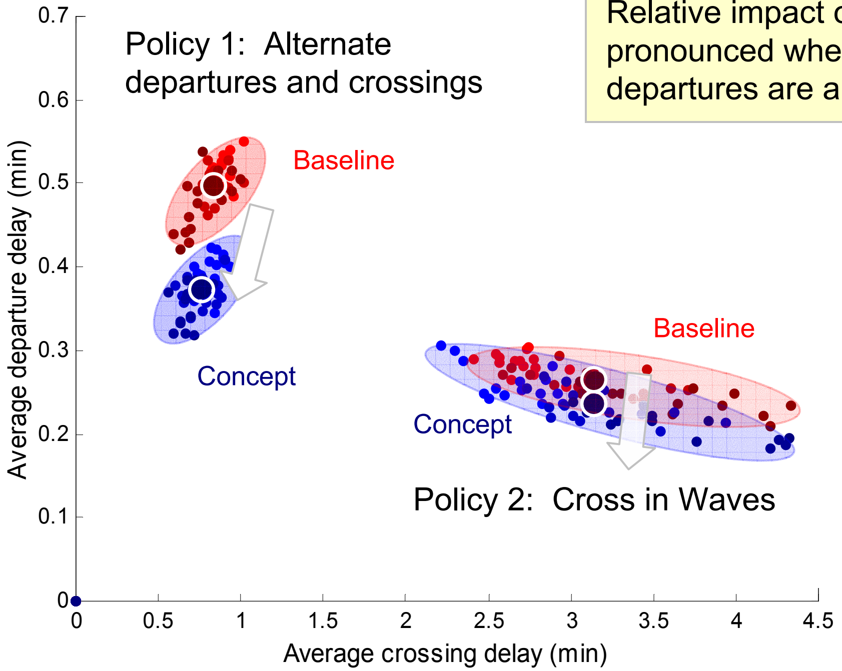


Runway Crossing : Crossing Policy Comparison

- **Departures on the Inboard Runway**

Reduces the average departure delay under both crossing heuristics

Relative impact on arrival delay is more pronounced when crossings and departures are alternated



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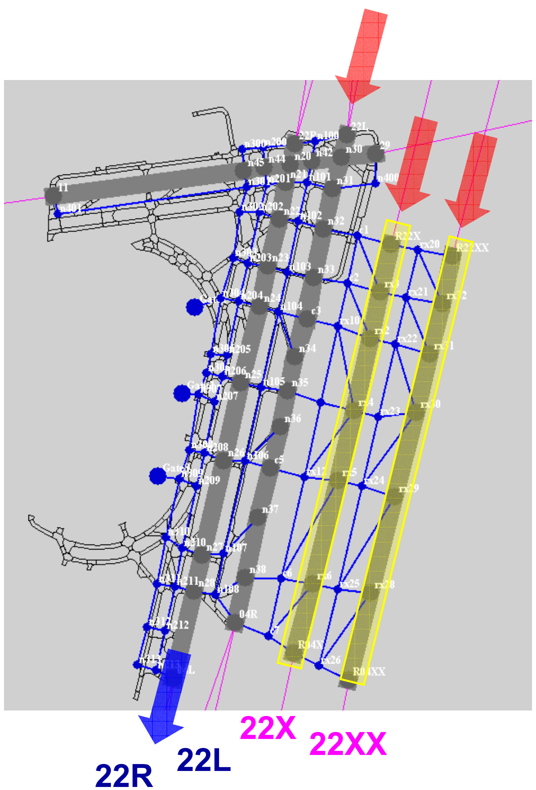
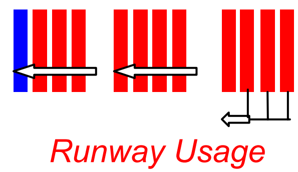
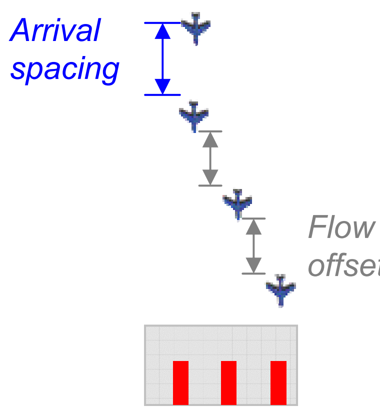
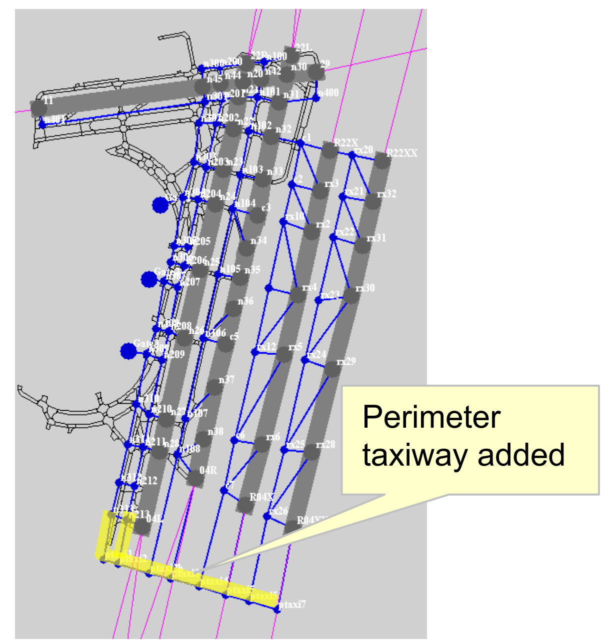
Runway Crossing Behavior: Multiple Crossings

- **Additional runways at EWR modeled**
- **Emulate crossings required for landing on CSPR**
- **Also investigate impact of perimeter taxiway**









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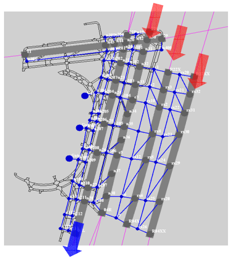
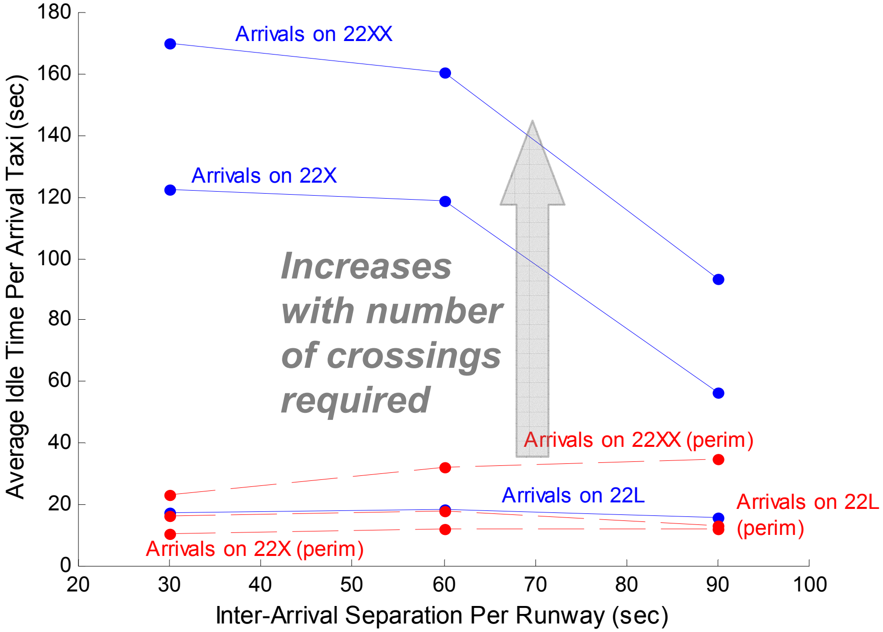
Runway Crossing Behavior: Results (1a)

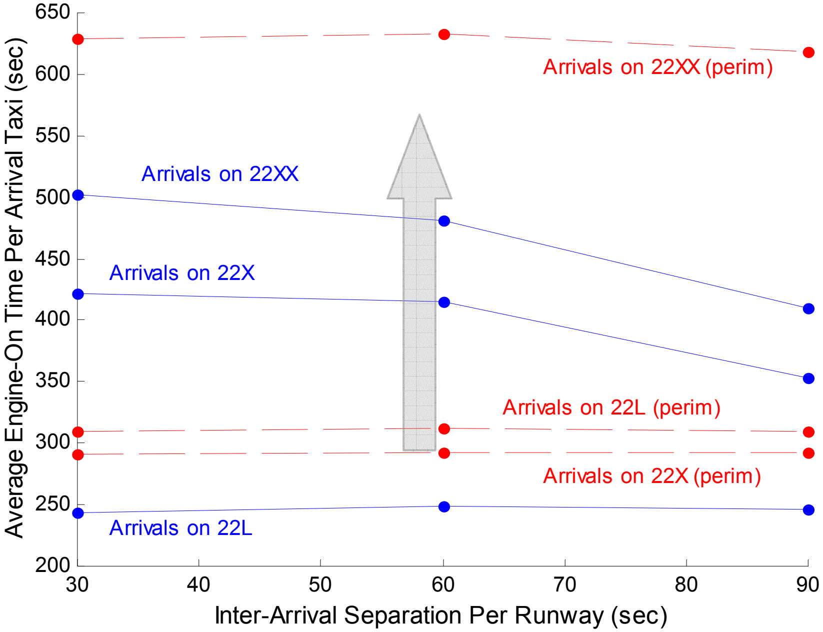
- **Departures inboard on 22R**
- **Increasing use of outboard arrival runways**
- **Variation in inter-arrival separation**



Average time stopped per arrival flight

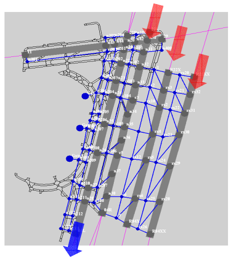


Average engine-on time per arrival flight

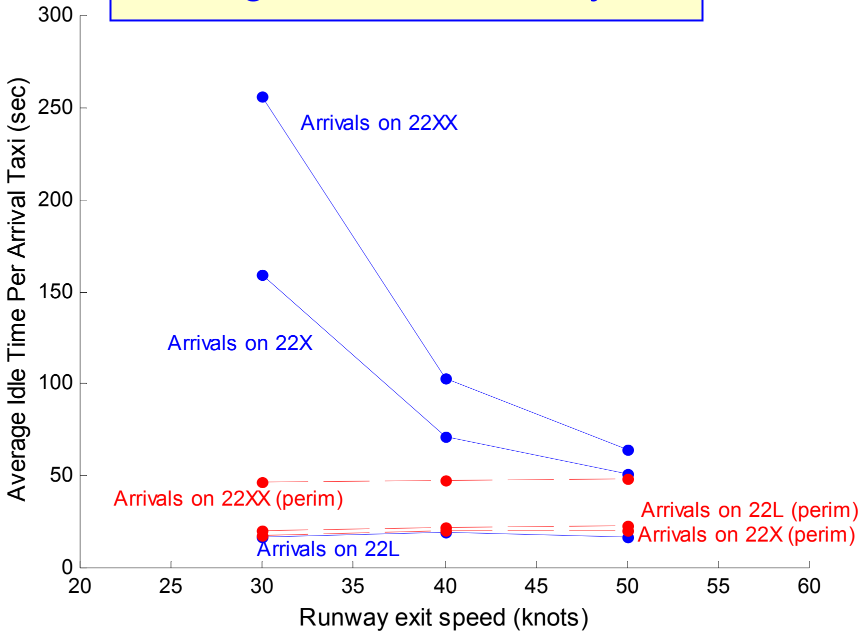


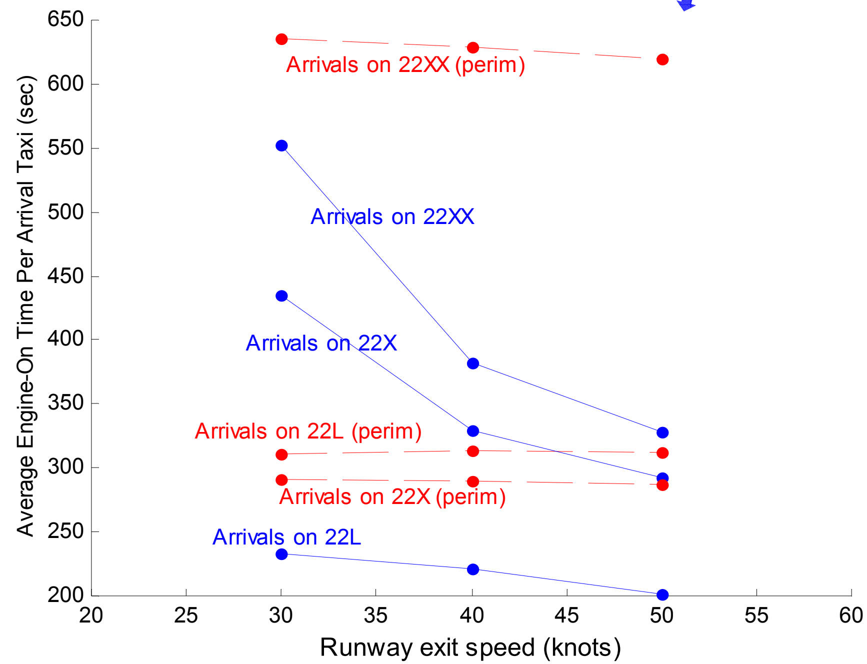
Runway Crossing Behavior: Results (1b)

- **Departures inboard on 22R**
- **Examine variation with runway exit speed**



Average arrival taxi delay



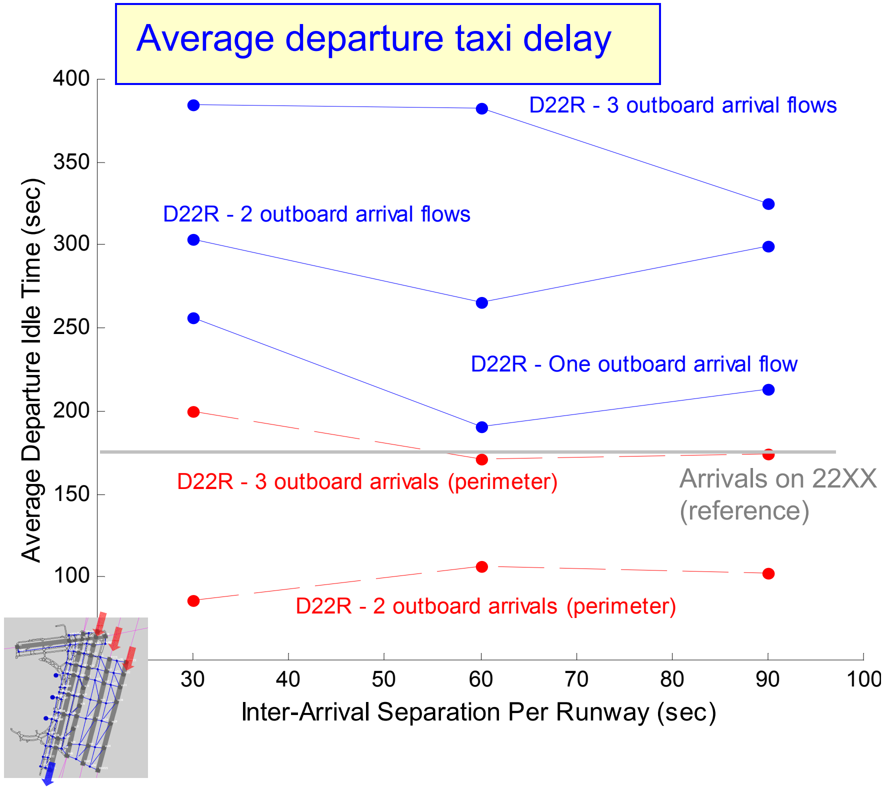


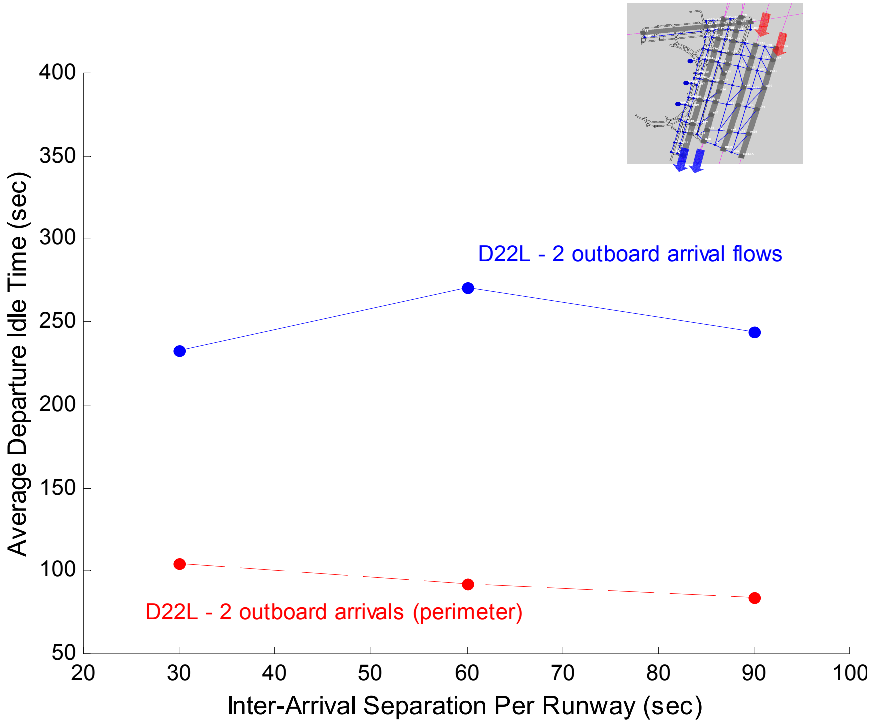
Average arrival engine-on time

METRON AVIATION

Runway Crossing Behavior: Results(1c)

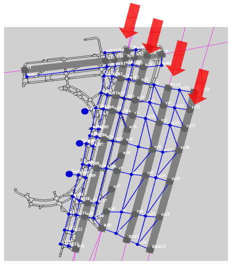
- **Examine <u>Departure Delay</u> for Flights on Inboard Runway (22R) and Runway (22L)**
- **Variation with inter-arrival spacing**

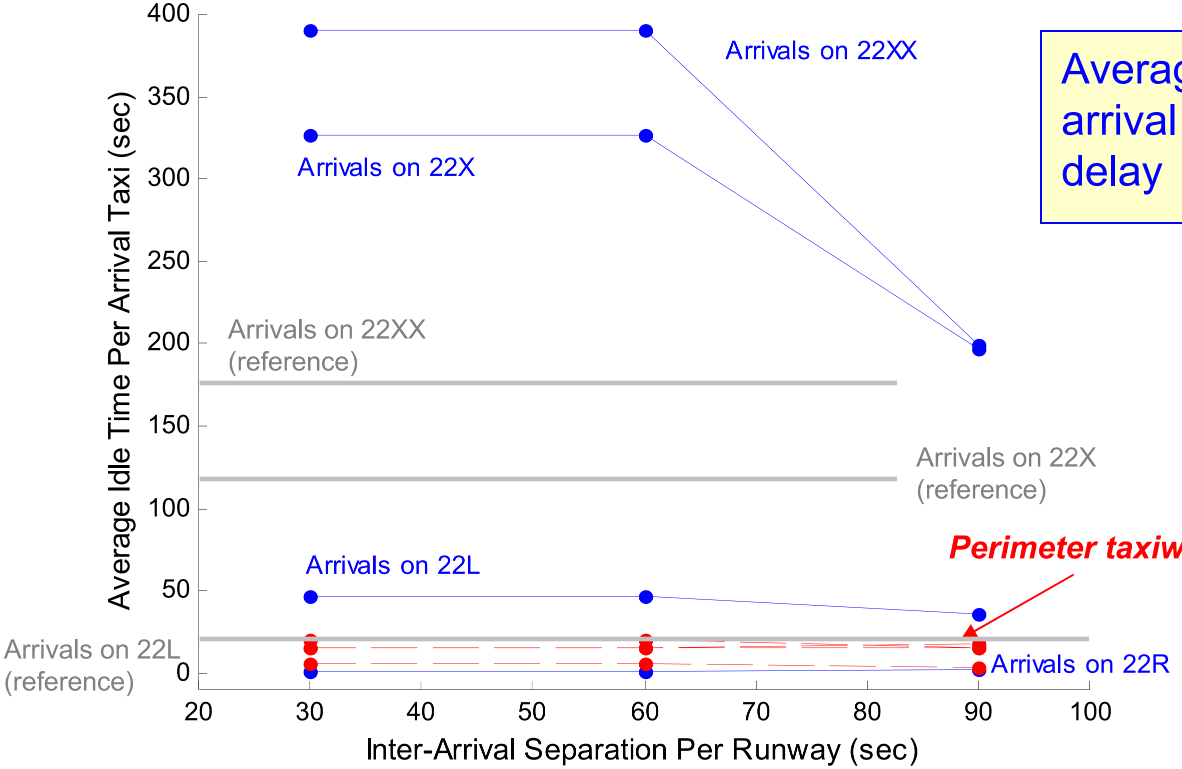




Runway Crossing Behavior: Results (2a)

- **Arrivals <u>on all runways</u>**
- **Variation in inter-arrival spacing**



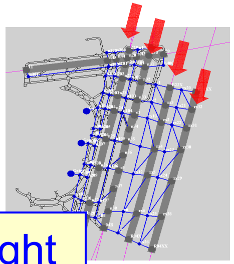


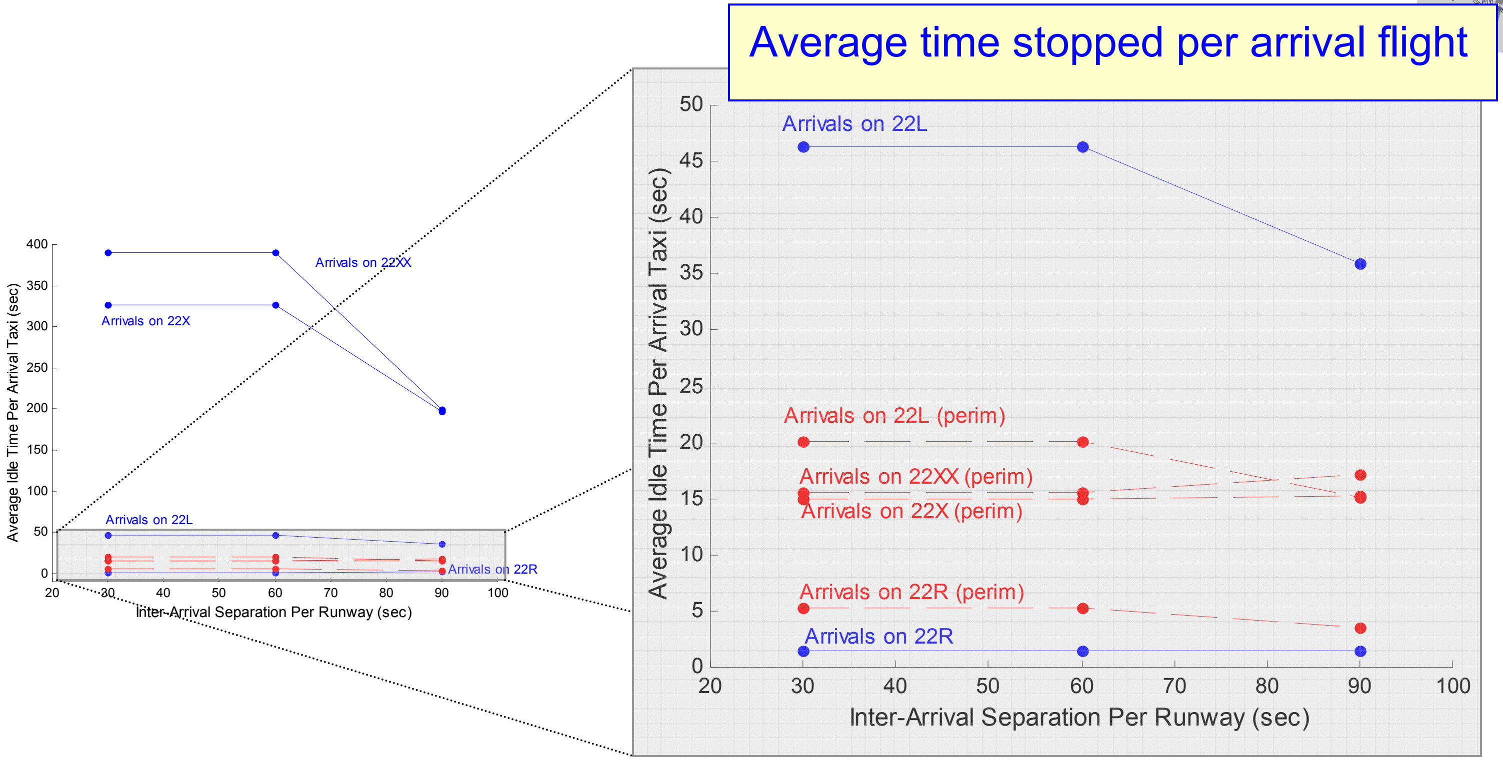
Average arrival taxi delay

METRON AVIATION

Runway Crossing Behavior: Results (2b)

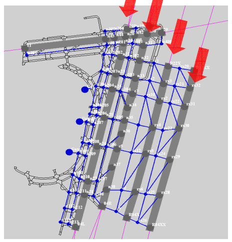
- **Arrivals <u>on all runways</u>**
- **Variation in inter-arrival spacing**

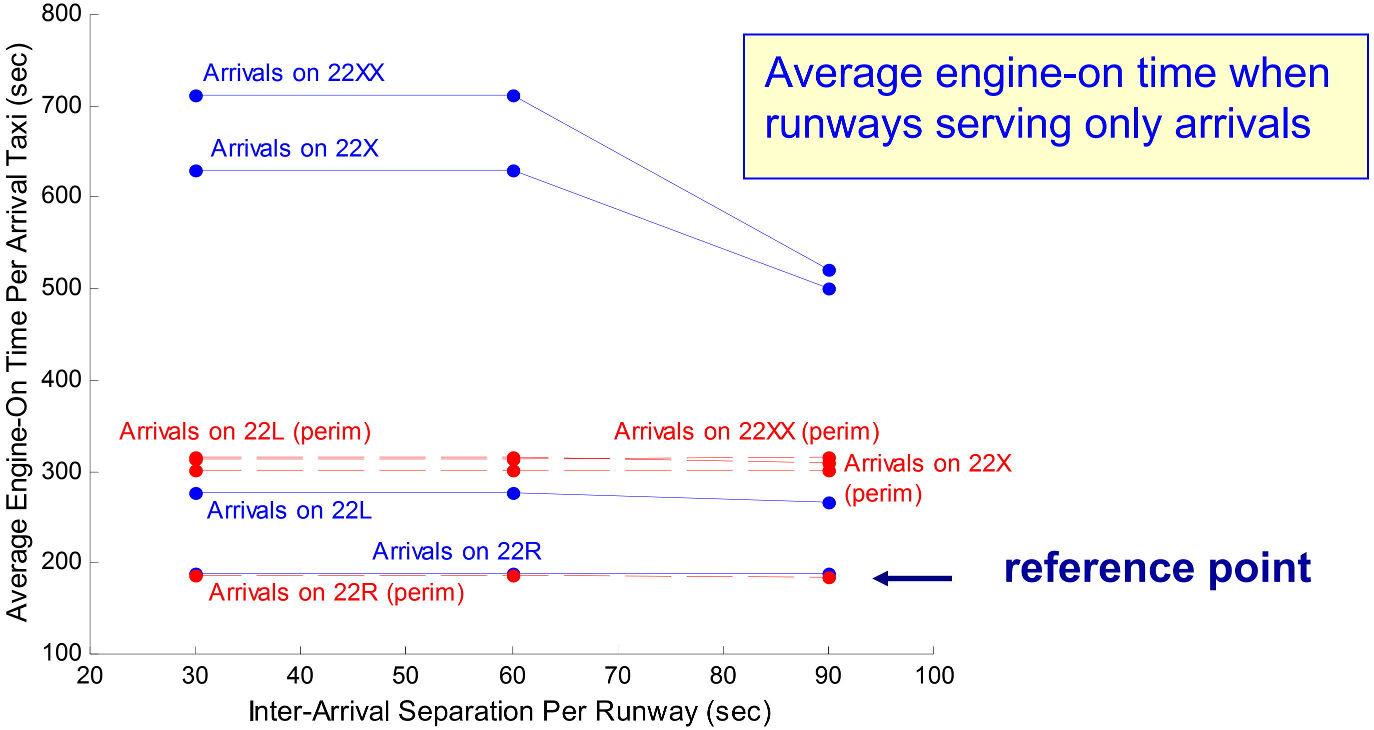




Runway Crossing Behavior: Results (2c)

- **Arrivals <u>on all runways</u>**
- **Variation in inter-arrival spacing**

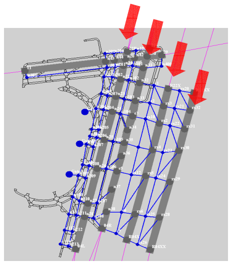


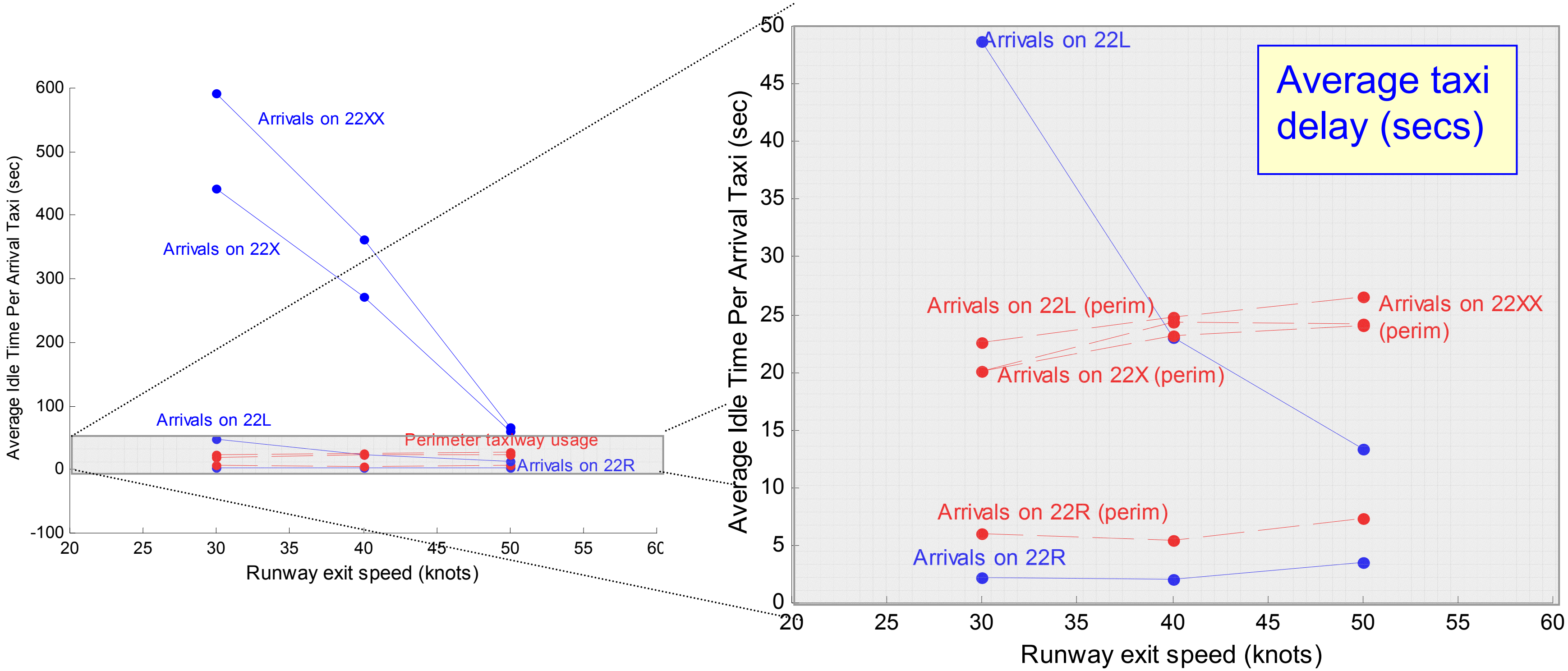


METRON AVIATION

Runway Crossing Behavior: Results (2d)

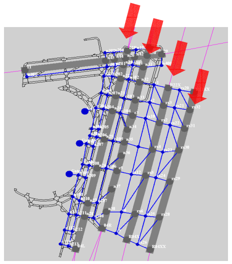
- **Arrivals <u>on all runways</u>**
- **Variation with runway exit speed**

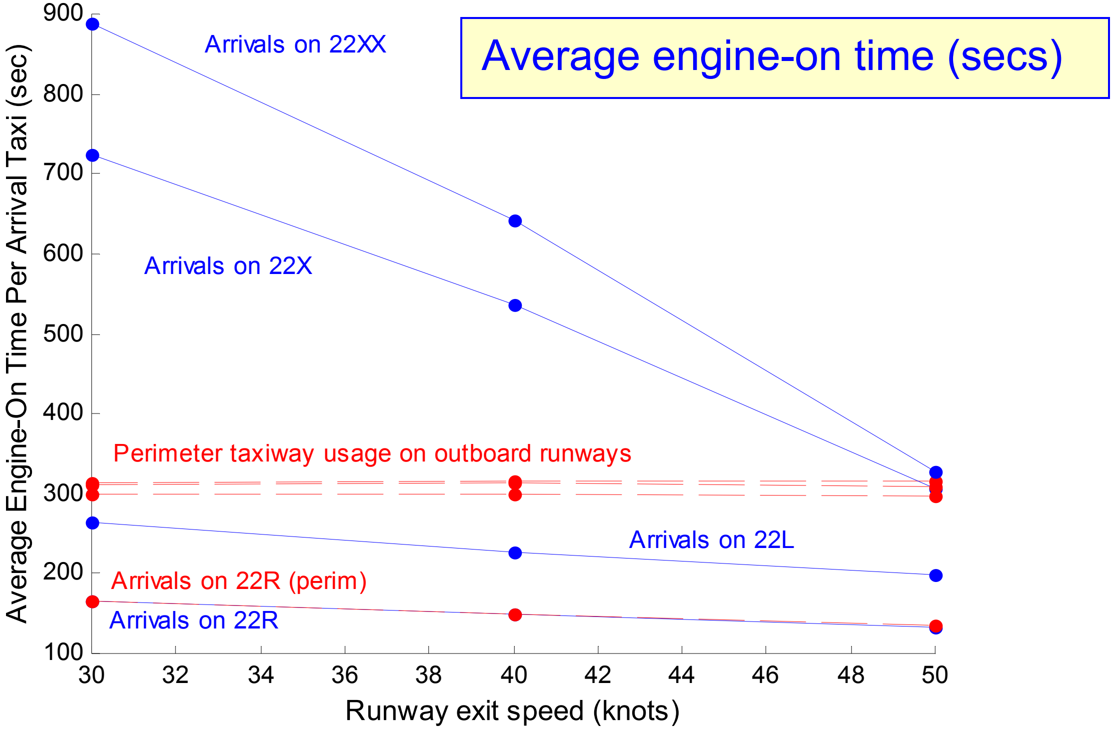




Runway Crossing Behavior: Results (2e)

- **Arrivals <u>on all runways</u>**
- **Variation with runway exit speed**

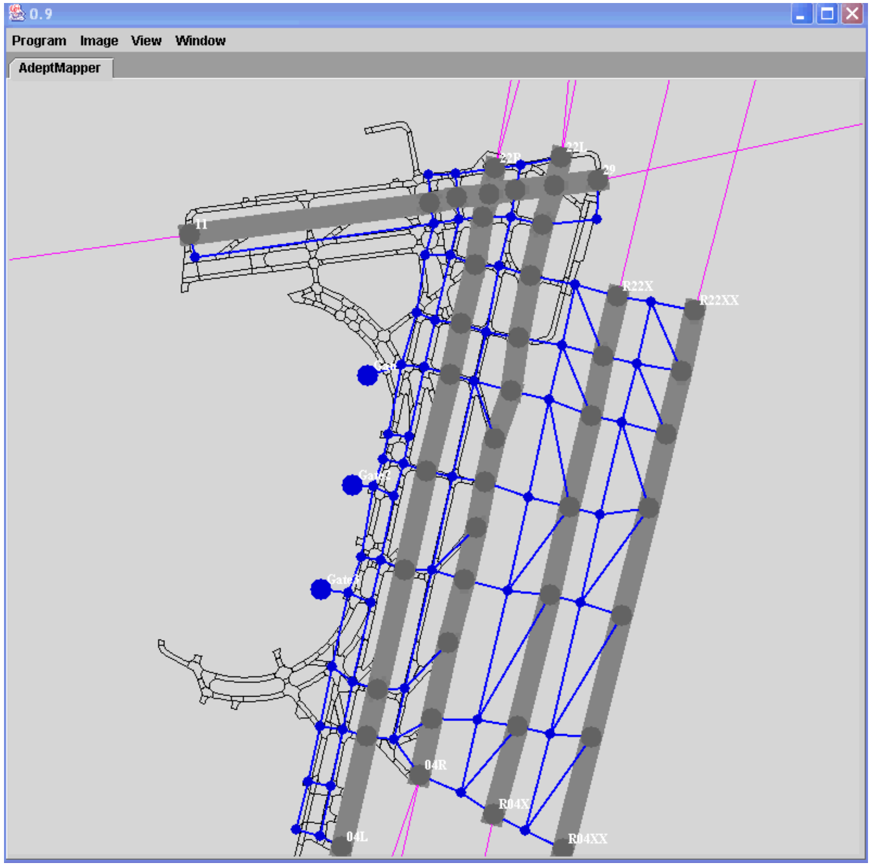




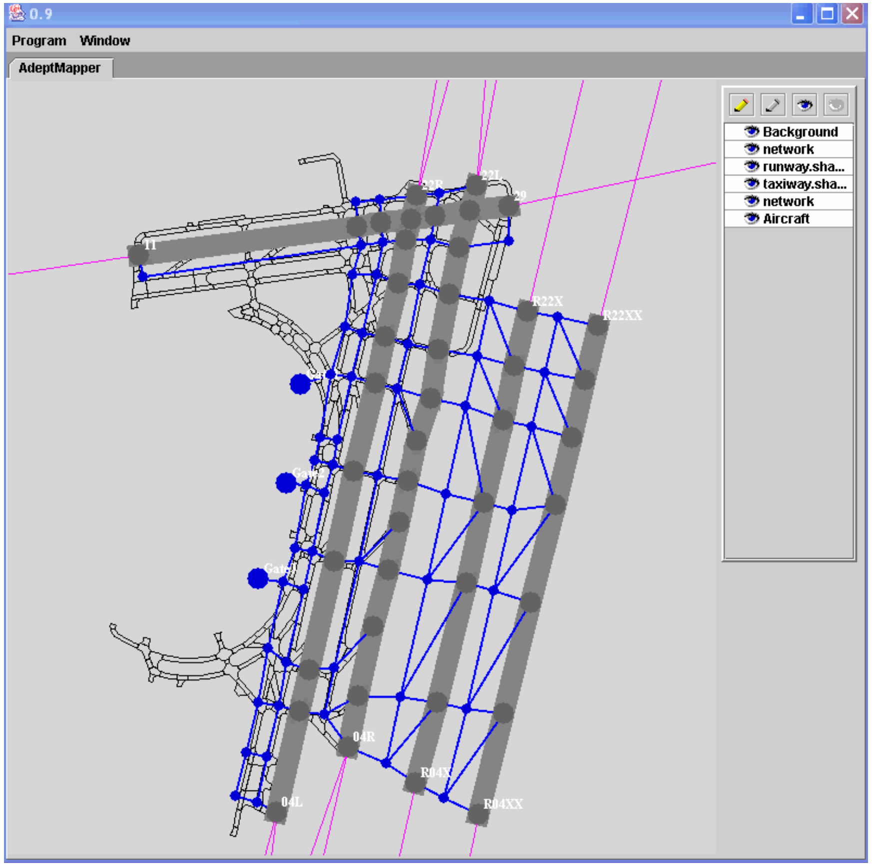
METRON AVIATION

Runway Crossing Behavior: Illustrative Examples

Departures 22R, Arrivals 22L, 22X, 22XX



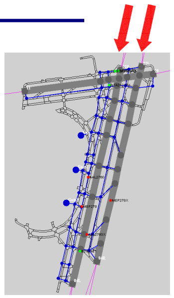
Arrivals on all runways

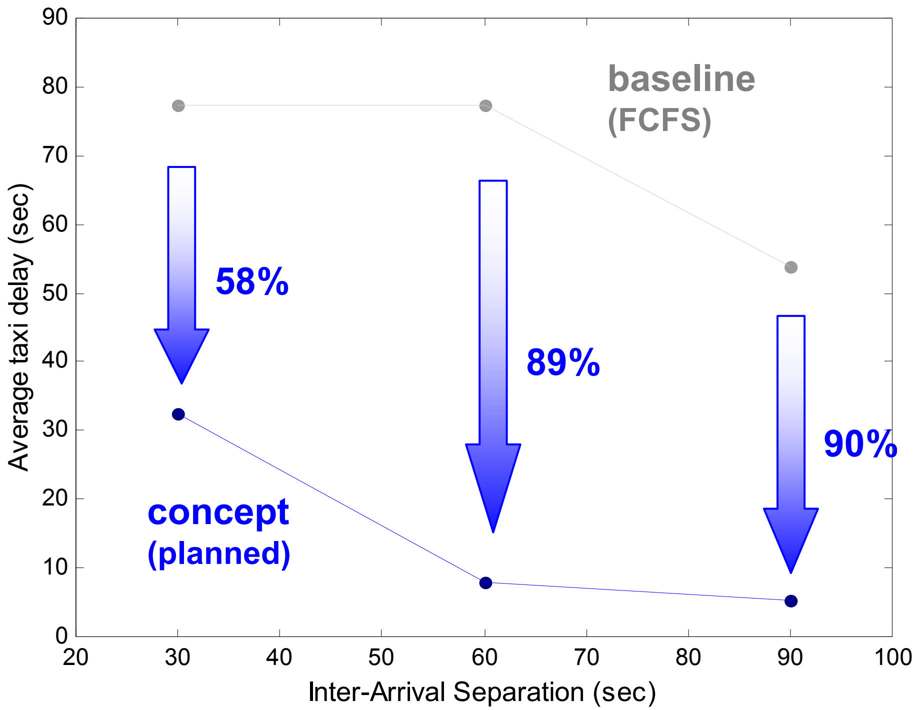


METRON AVIATION

Runway Crossing Behavior: Impact of Planning

- **Arrivals on 22L, 22R**
- **Planner finds shortest-time path for each flight**
- **Sequentially constrained network search**

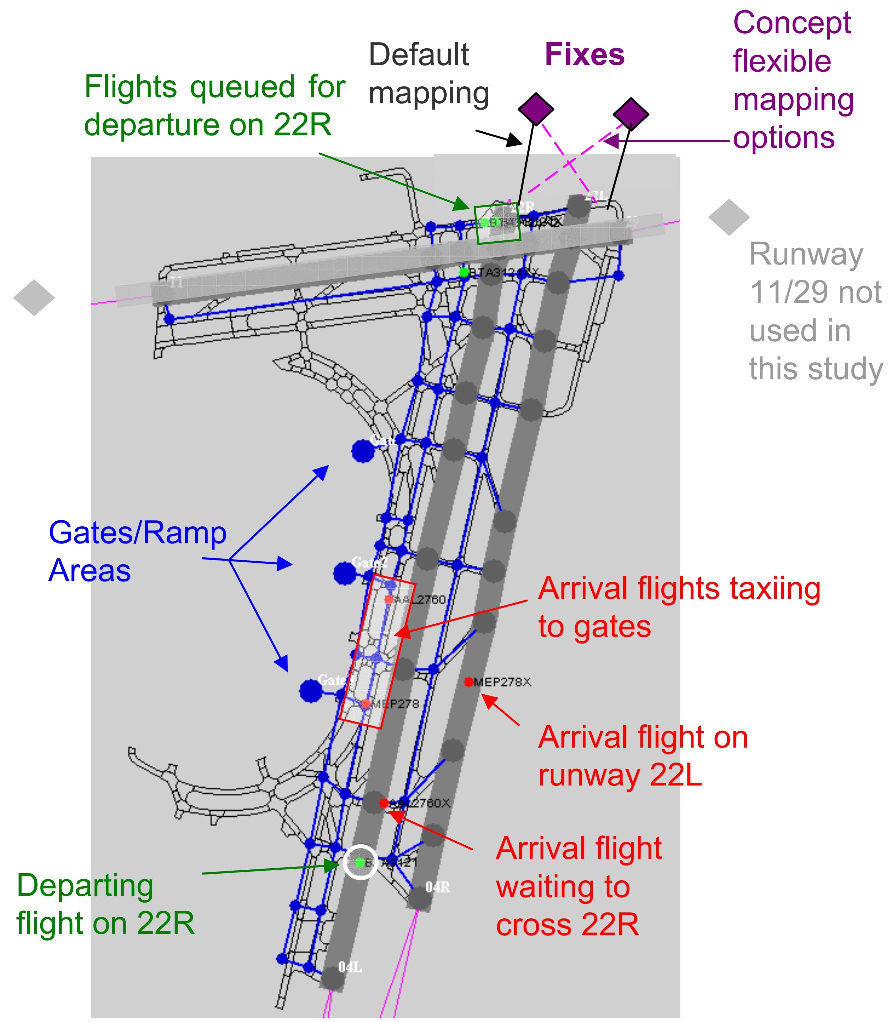




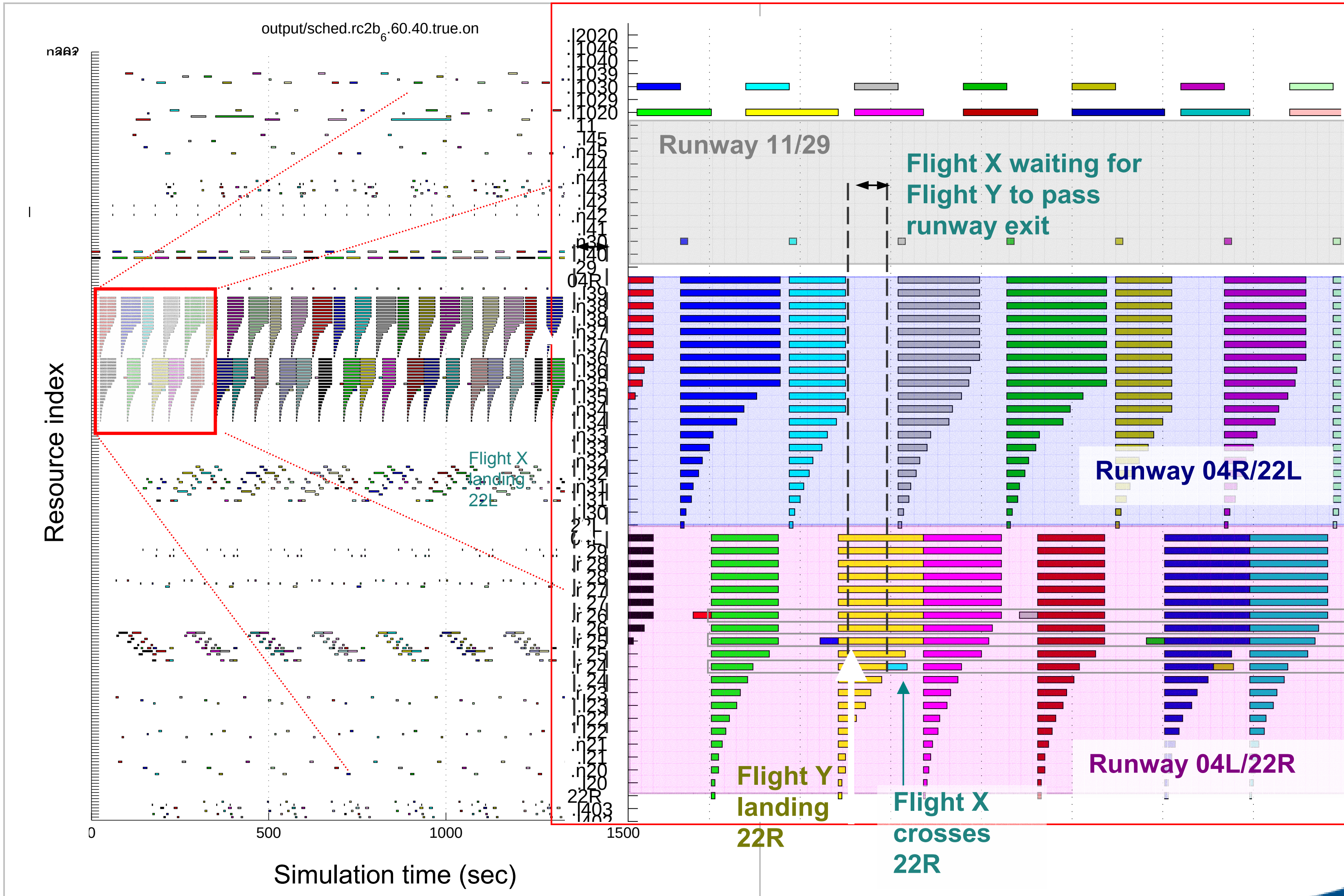
Explicit planning of surface routings and coordination with terminal airspace provides significant reductions in taxi delay

Technical Feasibility Experiments

- **Approach:**
  - Physical modeling of aircraft movements
  - Algorithms for resource allocation
- **Goals:**
  - Establish feasibility of conflict-free planning
  - Assess benefits of *explicit planning* of conflict-free routes
  - Assess benefits of *flexible* terminal area routing



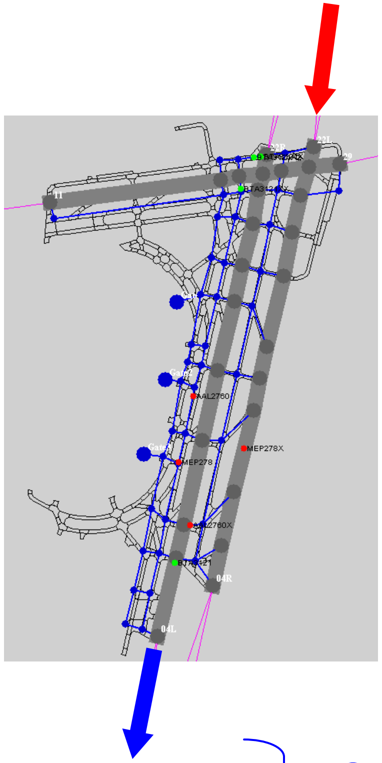
Technical Feasibility: Scheduling Model



METRON AVIATION

Approach: Planning at EWR

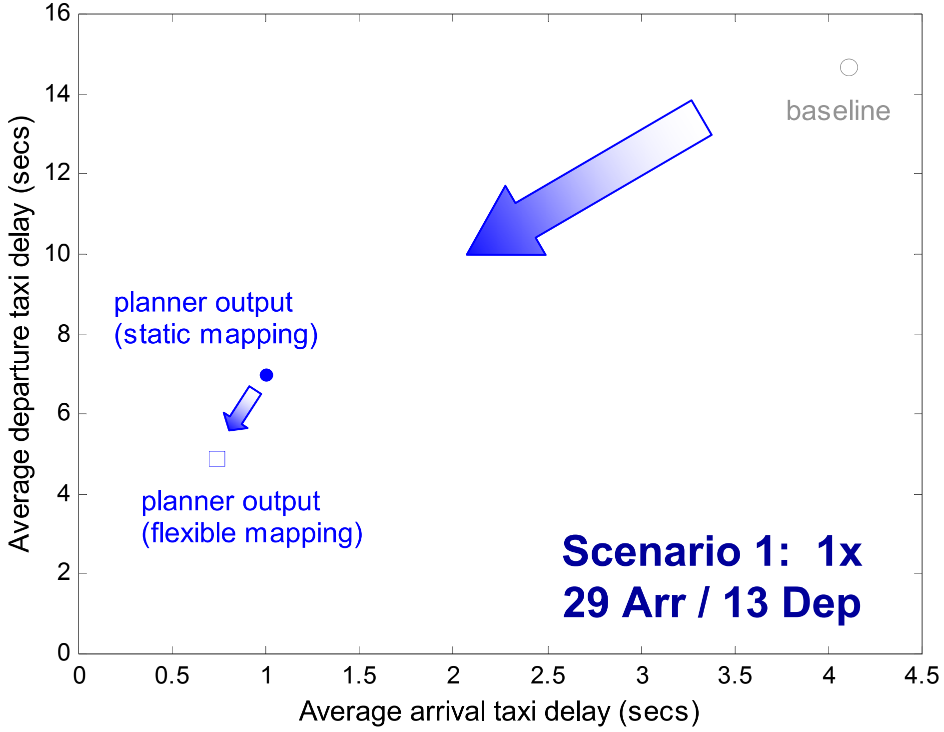
- **Arrival and Departure Demand – based on 5/17/2002, 1 hour of data**
- **Scenario 1**
  - Arrivals at runway (1x = 29)
  - Departures at gates (1x = 13)
- **Scenario 2**
  - Arrivals at runway (1x = 29)
  - Departures at gates (1x = 26)
- **Resource allocation schemes:**
  - Baseline (FCFS)
  - Shortest-time Paths, Static Fix-Runway Mapping
  - Shortest-Time Paths, Flexible Fix-Runway Mapping



Sequentially constrained network

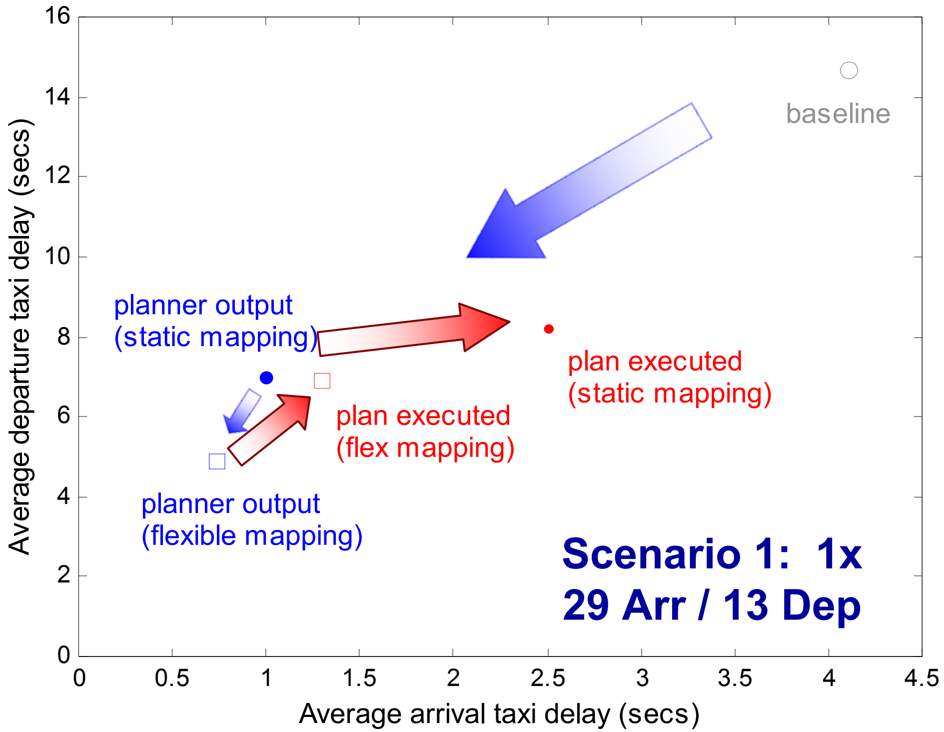
Results: Planning at EWR (1x traffic)

- **Impact of Explicit Planning – Assuming Plan Executed Perfectly**



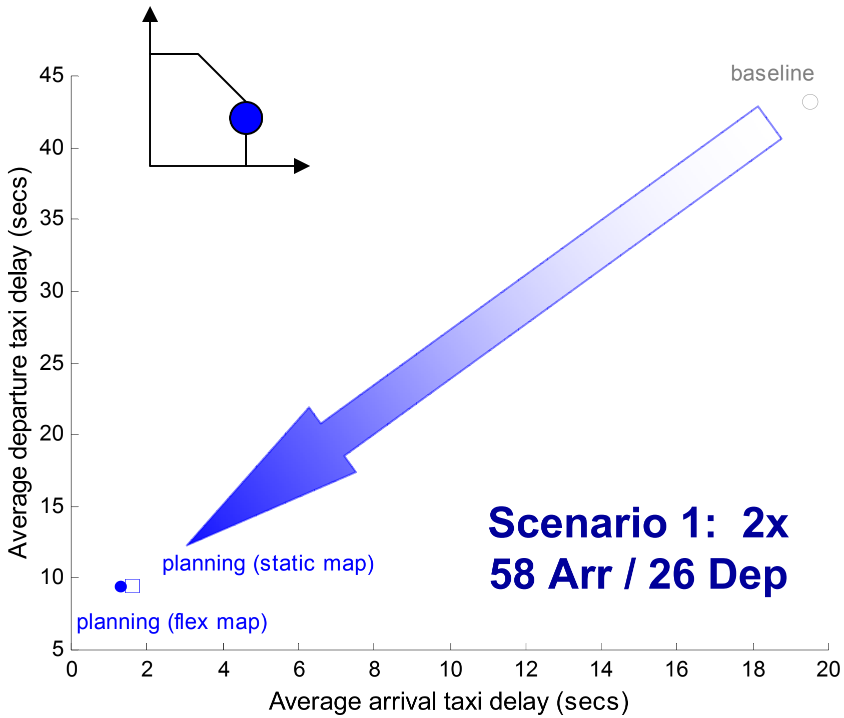
Results: Planning at EWR (1x traffic)

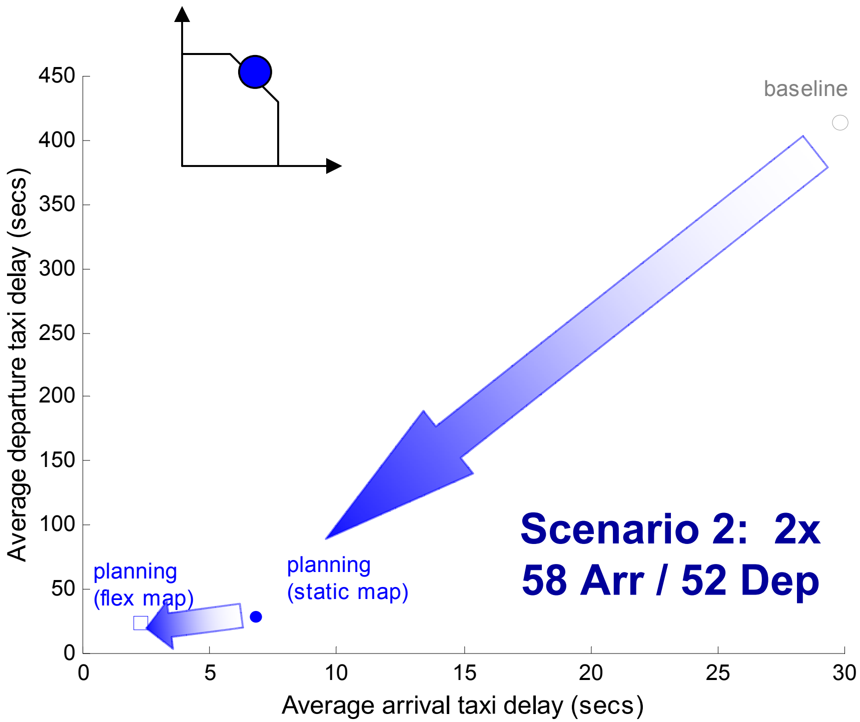
- **Effect of Imperfect Execution – highlights the need for Clearance Manager, Dynamic Re-planner**



Results: Planning at EWR (2x traffic)

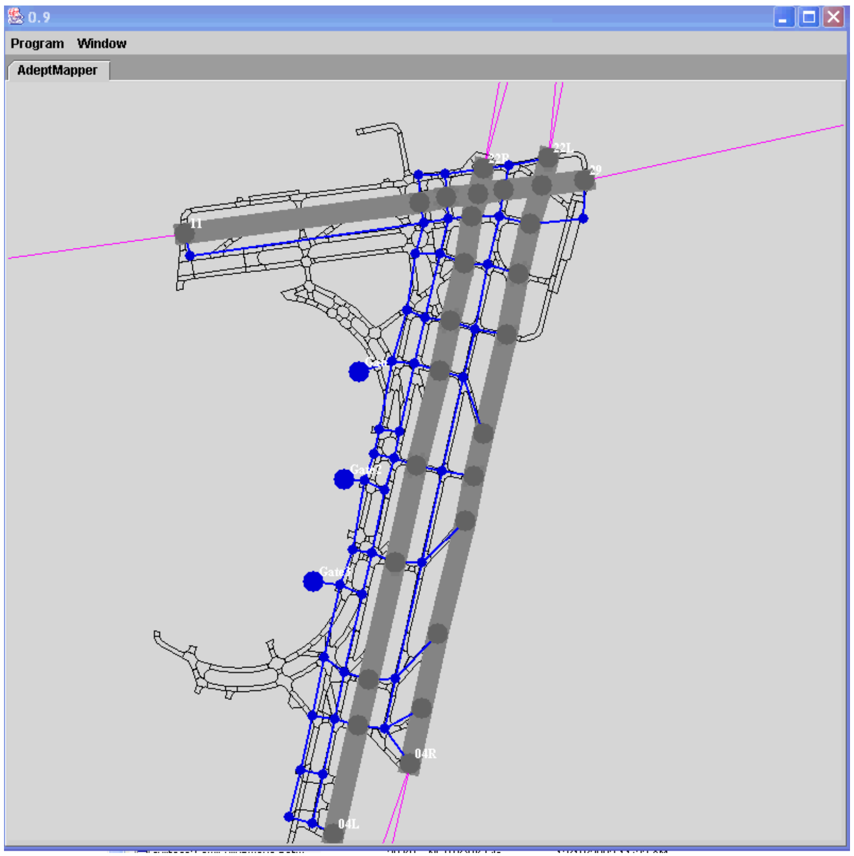
- **Impact of Explicit Planning – Assuming Plan Executed Perfectly**



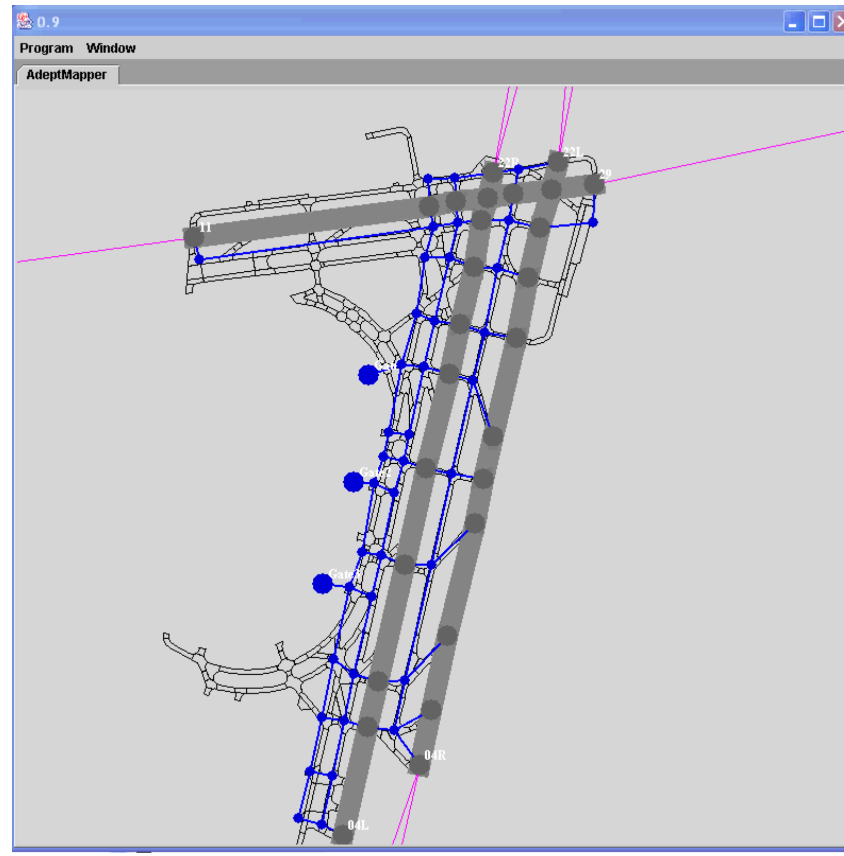


Planning: Results at EWR (2x traffic)

- **Movie 1**
  - Scenario 2(2x) ,No planning

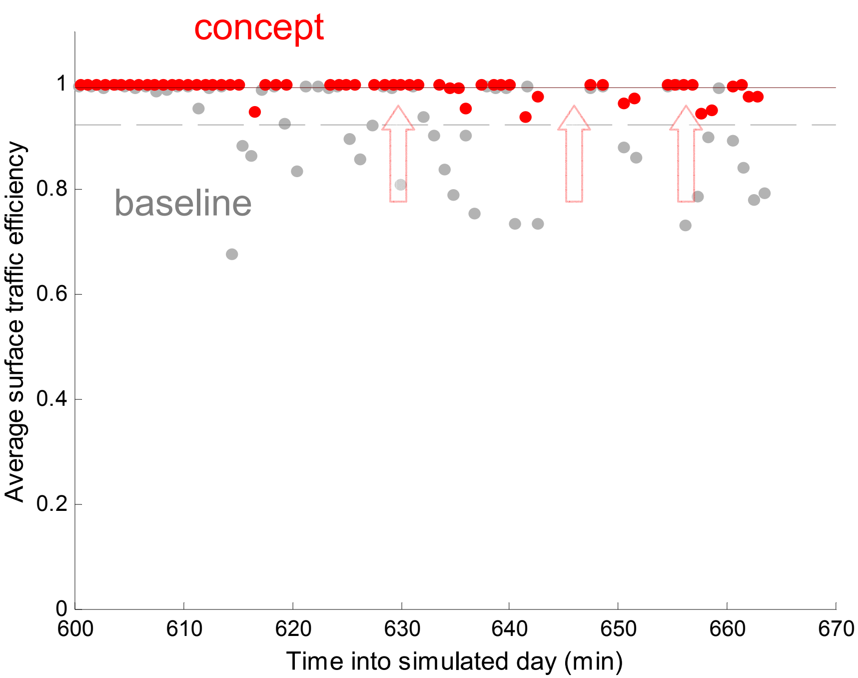


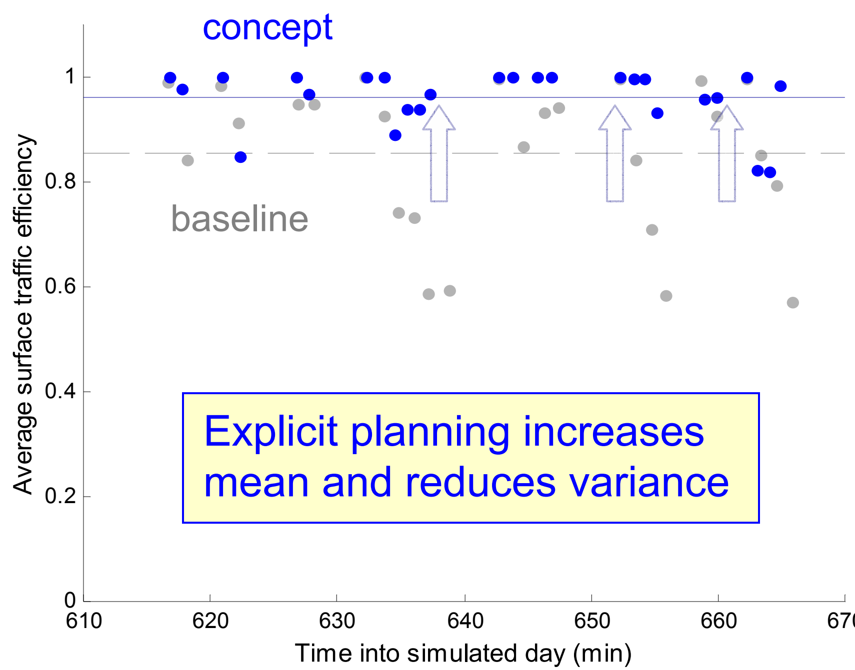
- **Movie 2**
  - Scenario 2 (2x), Planning



Results: Planning at EWR (2x traffic)

- **Surface Efficiency variation – Scenario 2**





METRON AVIATION

Technical Feasibility: Experiment Results Summary

	Planned			Actual		
Scenario	Ave Engine-On Time (sec) A | D	Ave Taxi Delay (sec) A | D	# of Stop/ Starts A | D	# of Stop/ Starts A | D	Ave Engine-On Time (sec) A | D	Ave Taxi Delay (sec) A | D
Experiment 1: 1x Demand – Arrivals 29, Departures 13						
No Plan 1x				0 | 3	219.1 | 206.8	4.10 | 14.7
Static Map 1x	189.5 | 204.6	1.0 | 7.0	0 | 2	0 | 0	219.4 | 208.2	2.5 | 8.2
Flex Map 1x	169.1 | 201.2	0.74 | 4.9	0 | 0	0 | 0	194.3 | 205.0	1.3 | 6.9
No Plan 2x				**11 | 15**	230.5 | 239.9	19.5 | 43.2
Static Map 2x	189.2 | 220.1	1.3 | 9.4	**0 | 3**	12 | 5	230.5 | 240.1	20.8 | 31.2
Flex Map 2x	175.4 | 207.3	1.6 | 9.5	**1 | 1**	18 | 2	222.4 | 226.5	29.6 | 33.4
Experiment 2: 1x Demand – Arrivals 29, Departures 26						
No Plan 1x				**1 | 15**	224.4 | 238.7	9.1 | 39.7
Static Map 1x	191.7 | 220.8	3.2 | 10.3	**0 | 4**	2 | 9	226.8 | 242.4	13.7 | 32.7
Flex Map 1x	174.8 | 206.8	3.9 | 8.9	**2 | 1**	2 | 4	201.1 | 222.4	9.7 | 27.3
No Plan 2x				**18 | 310**	240.7 | 610.3	29.8 | 414
Static Map 2x	194.5 | 329.4	6.8 | 29.4	**3 | 16**	24 | 231	248.6 | 632.5	42.6 | 355
Flex Map 2x	180.3 | 230.3	**2.3 | 23.4**	**0 | 8**	14 | 52	227.6 | 308.1	26.2 | 120

Conclusions

- **Viable approaches to evaluating concept benefits have been derived**
- **Initial estimates of benefits and performance trends look promising**
- **Self-assessment has provided insight into concept functions and requirements**
- **Opportunities for blending with other concepts in other domains have been identified**

Transferability to ACES

- **Flexible Runway Assignment**
  - Effective scaling of the airport departure rate
- **Pushback Scheduling**
  - Add logic to the Airport Traffic Management agent in ACES
- **Configuration Change Efficiency**
  - Define transient throughput loss relationship as a function of demand level at the time of configuration change, varies based on “A” to “B” configurations.
- **EDCT Compliance**
  - Integrate “advance/delay” logic into ACES to allow flights to be moved forward and backward in the runway schedule.
  - Issue: does any “downstream” ACES agent care?
- **Runway Crossing Efficiency**
  - Scale the taxi delay for different airport crossing geometries as a function of the runway assigned to each arrival flight.

Next Steps – Challenges

- **Phase Three Evaluation with ACES**
  - Continue to refine local relationships to shape input files and ACES agent behavior (per-airport)
  - Patch together local scenarios to create NAS-wide cases for evaluation with ACES
- **Phase Three Technical Feasibility**
  - Real-Time Clearance Manager Function
  - Dynamic Planner Function
  - Departure Constraint Manager Function
  - Conformance Monitor Function
  - Explore sensitivity to uncertainty

Also focus on user interface and demonstrate HITL interaction with automation

- **Phase Three Multi-Domain Evaluation**
  - Incorporate Wx Re-routing Algorithms
  - Incorporate CSPR ideas from TACEC
  - Begin to investigate en route merging algorithms